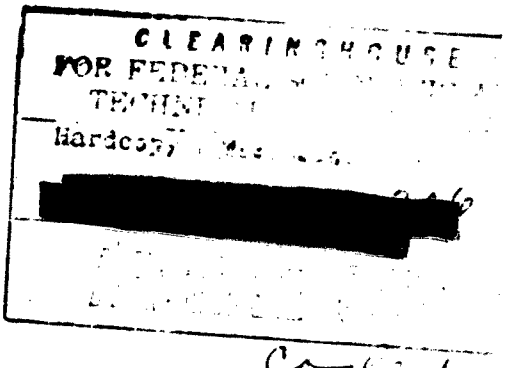
ENGINEERING STUDY OF ATOMIC BLA
RESISTANT DESIGN FOR
SEVERAL DIFFERENT BUILDING TYPE



A REPORT SUBMITTED
TO
THE OFFICE OF THE CHIEF OF ENGINEERS
DEPARTMENT OF THE ARMY
UNDER
CONTRACT DA 49-129-ENG 317

AMMANN & WHITNEY
CONSULTING ENGINEERS

MAR 1960

1.

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CHAPTER 1 - INTRODUCTION

1.1 OBJECTIVES

This report summarizes the results of an engineering study of several building types to determine (a) the practicability of design for atomic blast resistance, (b) the estimated construction cost for a range of blast pressure loadings and a comparison of costs with conventional construction, and (c) the estimated additional cost of providing personnel shelter areas.

The blast resistant designs and construction cost estimates have been prepared for the following building types and peak incident blast pressures.

Standard Structures

1. Administration Building, Two Story for 10, 20 and 30 psi.
2. Communications Building for 10, 20 and 30 psi.
3. Warehouse for 10, 20 and 30 psi.

Nonstandard Structures, General Purpose

4. Concrete Igloo for 25, 50, 100 and 200 psi.
5. Earth Covered, Concrete Rectangular, 40' x 80', for 25, 50, 100 and 200 psi.
6. Earth Covered, Concrete Double Barrel Arch, 40' x 80' usable floor area, for 50 psi.
7. Earth Covered, Concrete Dome, 25' diameter for 50, 100 and 200 psi.

8. Buried, Concrete Rectangular,
   40' x 80', for 50, 100 and 200 psi.
9. Buried, Concrete Double Barrel Arch,
   40' x 80' usable floor area, for 50 psi
10. Buried, Concrete Dome,
    25' diameter, for 50, 100 and 200 psi.
11. Buried, Concrete Igloo,
    26'-10" x 60'-8" for 50, 100 and 200 psi.

1.2 DESIGN BLAST LOADS

The blast loadings on the structures are based upon the peak incident pressures listed in Section 1.1. All calculations relative to the blast loadings, except as noted, are based upon the preliminary draft of the Corps of Engineers Manual EM1110-345-413, "Design of Structures to Resist the Effects of Atomic Weapons (hereinafter referred to as the C of E Manual) - Weapons Effects Data". The assumed durations of the incident blast pressure waves are as follows:

Peak incident pressure, psi	10	20	25	30	50	100	200
Duration of positive pressure, sec. (C of E Manual)	1.55	1.21	1.12	1.05	0.85	0.64	0.43

1.3 DESIGN PROCEDURE

The design procedure and methods used, unless otherwise noted, are in accordance with the C of E Manual, EM1110-345-413 thru 421.

Roof and exposed floor slabs, walls, columns, footings and above ground earth covered arches are designed for plastic deformation under the design blast load. Above ground earth covered domes, buried arches, buried domes, blast doors and escape hatch doors are designed for maximum elastic deformation under design blast load.

The blast loads on walls of buried structures was taken as equal to the pressure at the ground surface (prescribed by OCE). On above ground earth covered structures, the pressures on the earth cover were first computed then the loads on the structure were found by using a "Mohr's Circle" Solution assuming a soil friction angle of 20 degrees.

1.4 MATERIALS AND STRESSES

The designs are based upon the following specifications and design stresses:

1. Reinforcing Bars: Intermediate grade in accordance with A.S.T.M. Specification Designation A305-56T and with Federal Specification QQ-B-71a. Yield point stress - 47,500 psi, increased approximately 10% to account for rapid rates of strain for most cases.
2. Structural Steel: A.S.T.M. Specification Designation A7-56T and Federal Specification QQ-S-741. Yield stress - 38,000 psi (corresponding to standard A.S.T.M. rate of loading) increased approximately 12.5% to account for rapid rates of strain for most cases.

3. Concrete: f'_c increased 30% to account for rapid rates of strain for most cases.

4. Foundation Bearing Pressure: 4 Tons/sq.ft., rated capacity (prescribed by OCE) 8 " " " ultimate capacity

1.5 RADIATION EFFECTS

Computations relative to the radiation level are based upon "Capabilities of Atomic Weapons" - Department of Defense Manual TM 23-200, June 1955, (secret). Neutron attenuation data was based upon " Informal AFSWP Data", March 1955. The required nuclear radiation protection, prescribed by the OCE, for the Non Standard Type Structures, Igloo and shelters of the Standard Type Structures was that the total gamma and neutron dosage be attenuated to 50 roetgens for the following weapons at any position producing a peak blast pressure equal to the design incident pressure:

Pressure level, psi.....	10	20	25	30	50	100	200
Yield (KT).....	20	20	20	20	100	200	500

1.6 ITEMS NOT INCLUDED IN STUDY

The following features were not included in this study and would be determined to suit the use requirements: - (1) mechanical equipment, including blast valves, chemical filters, and cooling water facilities, such as cooling towers, spray ponds or wells; (2) electrical equipment, (3) air locks and decontamination facilities; (4) button-up provisions; (5) duration of shelter occupancy, (6) standby equipment.

The drawings prepared under this contract (see Appendix H) are intended to depict the results of the design studies only. They are not standard drawings and are not intended to represent recommended designs. However they can be used for planning purposes and as the basis for development of required designs.

In the design of the exposed above ground structures the thicknesses of the walls and roofs were determined by blast resistance requirements only and therefore in some cases will not provide adequate shielding for fallout radiation. However, the earth covered and buried structures and the shelter areas in the exposed above ground structures have been designed to protect against the initial nuclear radiation as noted on the drawings and therefore afford adequate shielding from fallout radiation. The provision of adequate thickness in the walls and roofs of the Administration, Communication and Warehouse buildings to provide the required shielding from fallout radiation will require additional analysis which was not included in this contract.

CHAPTER 2 - DESCRIPTION OF STRUCTURE

2.1 ITEM NO. 1 - ADMINISTRATION BUILDING - TWO STORY (10, 20, 30 PSI)

2.1.1 General

The design of the Administration Building as shown on the Amasrm & Whitney Drawings No. 60-16-01 is adapted from drawing No. 30-02-02, sheet 1 of 27 through 27 of 27, entitled "Westover Air Force Base, Chicopee Falls, Massachusetts; Wing Headquarters Building, Corps of Engineers, U.S. Army, Office of the Division Engineer, New England Division, Boston, Massachusetts."

2.1.2 Existing Building

The exterior dimensions of the main wing of the existing two story building are 208'-6" x 65'-0". The smaller wing has exterior dimensions of 95'-0" x 49'-0". The exterior walls are constructed of 12" concrete block. The roof and floor systems are wood supported on wood joists which frame into steel girders. The minimum vertical clear distance is 9'-10-7/8" and 10'-3-1/2" for the first and second floors respectively. The ground floor slab is reinforced concrete on grade. There is a basement under the smaller wing containing the boiler rooms, storage space and other miscellaneous areas.

2.1.3 Blast Resistant Design (Fig. 1.1 - 1.3)

The proposed Blast Resistant Administration Building is a reinforced concrete, windowless structure with both utility

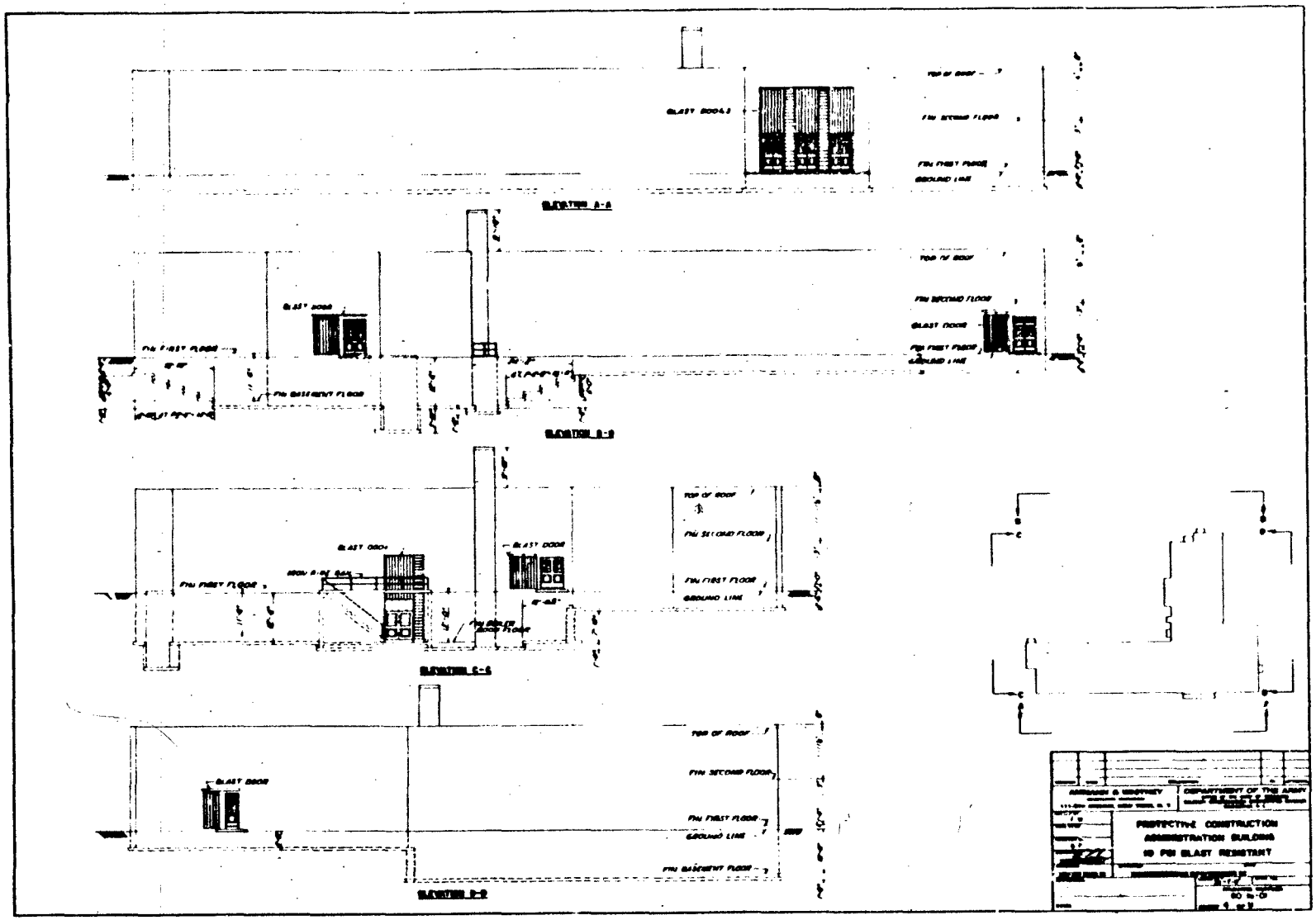

PROTECTIVE CONSTRUCTION
ADMINISTRATION BUILDING
10 PSI BLAST RESISTANT

Fig. 2.1

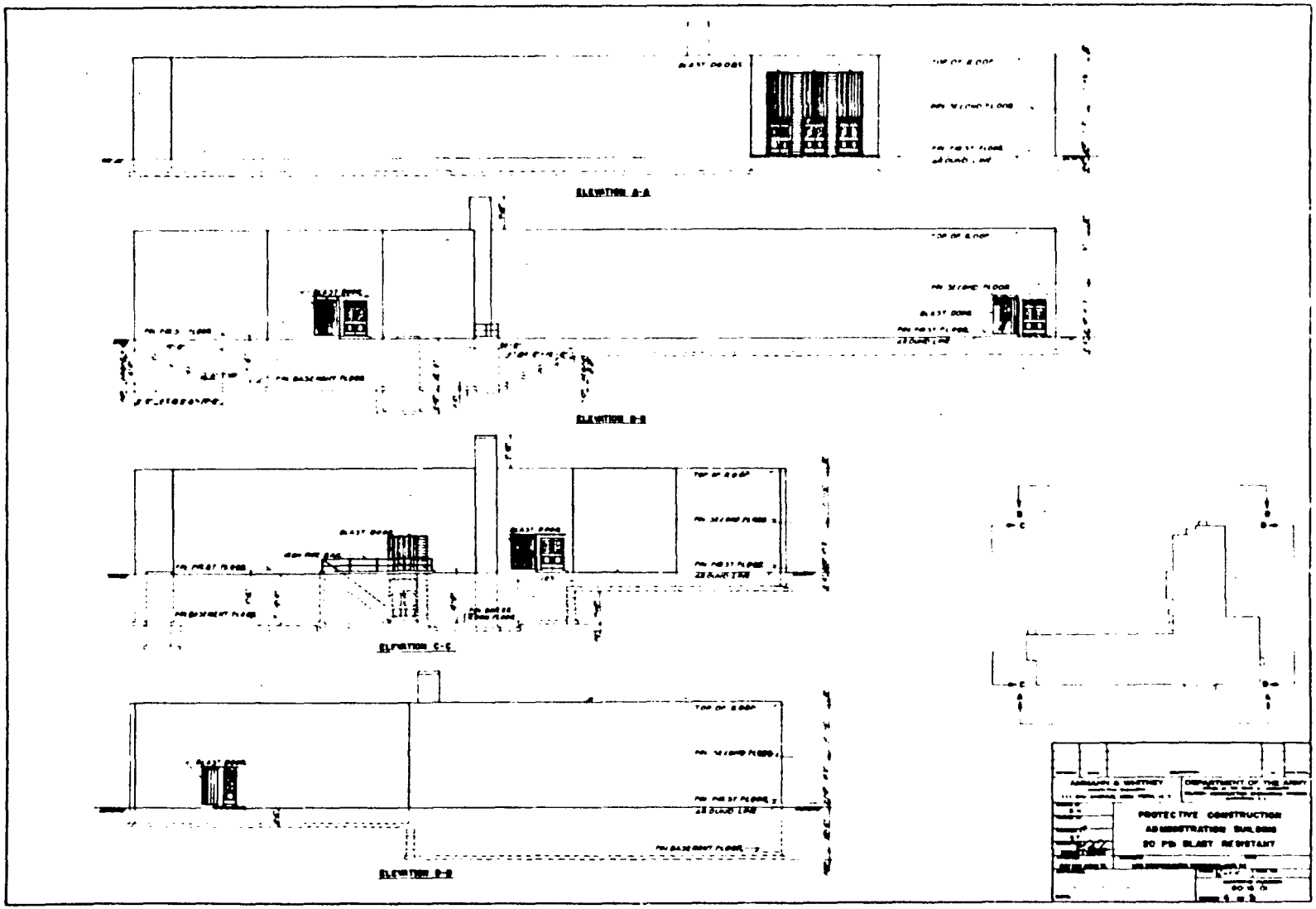


Fig. 2.2

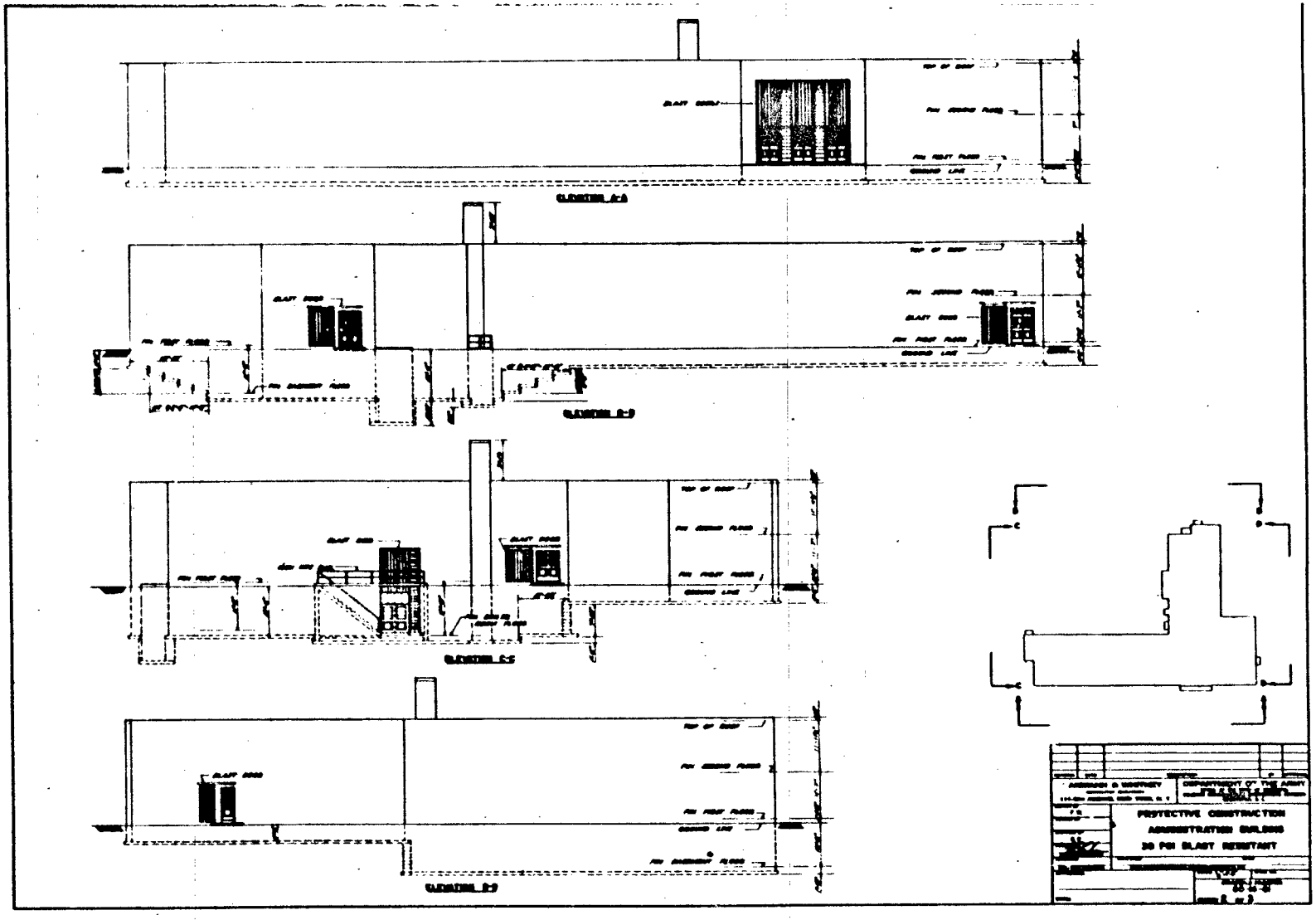

PROTECTIVE CONSTRUCTION
ADMINISTRATION BUILDING
30 PSI BLAST RESISTANT

Fig. 2.3

and blast doors at all exterior openings. The clear dimensions have been maintained essentially the same as those of the Westover Air Force Base structure.

The roof and floor systems are of beam and slab construction. The exterior wall panels are one way slabs spanning vertically between the floor levels. The roof and floor slabs are designed as deep beams to carry the wall panel blast loads. The concrete walls are utilized as shear walls to transmit the translational loads from the roof and floor slabs to the foundation. It was necessary to add an interior shear wall at column line 6.

A buried personnel shelter, for radiation and fallout protection, with a capacity of approximately 170 people (based upon 10 sq. ft. of floor area per person) is provided adjacent to the basement area. The earth cover over the shelter is controlled by radiation requirements.

The roof, walls, columns and footings are designed for plastic deformation. Blast doors are designed for maximum elastic deformation.

2.2 ITEM NO. 2 - COMMUNICATIONS BUILDING (10, 20, 30 PSI)

2.2.1 General

The design of the Communications Building as shown on Ammann & Whitney Drawings No. 60-02-56 is adapted from drawings No. 38-04-01 Sheet 1 to 9 of 9 sheets, entitled "McGuire Air Force Base, Wrightstown, New Jersey; Base Communication Center,

Corps of Engineers, U. S. Army, Office of the District Engineer, Philadelphia, Pennsylvania, (9 December 1952)".

2.2.2 Existing Building

The interior dimensions of the main wing of the existing building are 177'-6" x 25'-4" (23'-4" in office area). The smaller wing of the building contains the garage (20'-0" x 22'-0"), the heat exchange room (14'-0" x 22'-0"), and the motor generator room (9'-10" x 16'-0"). The walls are concrete block bearing walls. The roof system is a 2-1/2" concrete slab resting on bar joists. The clear distance from top of finished floor to bottom of finished ceiling is 10'-6". The floor slab rests upon a 6" cinder fill. Excavation is not required except for footings and the cable vault.

2.2.3 Blast Resistant Design (Fig. 1.4 - 1.6)

The proposed Blast Resistant Communication Building is a reinforced concrete, windowless structure with both utility and blast doors for all openings. The clear dimensions have been maintained essentially the same as those of the McGuire AFB structure.

The roof of the main wing is of beam and slab construction. The slab is continuous over an interior longitudinal shallow beam supported by a row of columns along the centerline of the structure. The roof of the small wing is two way slab construction. The garage is not blast resistant.

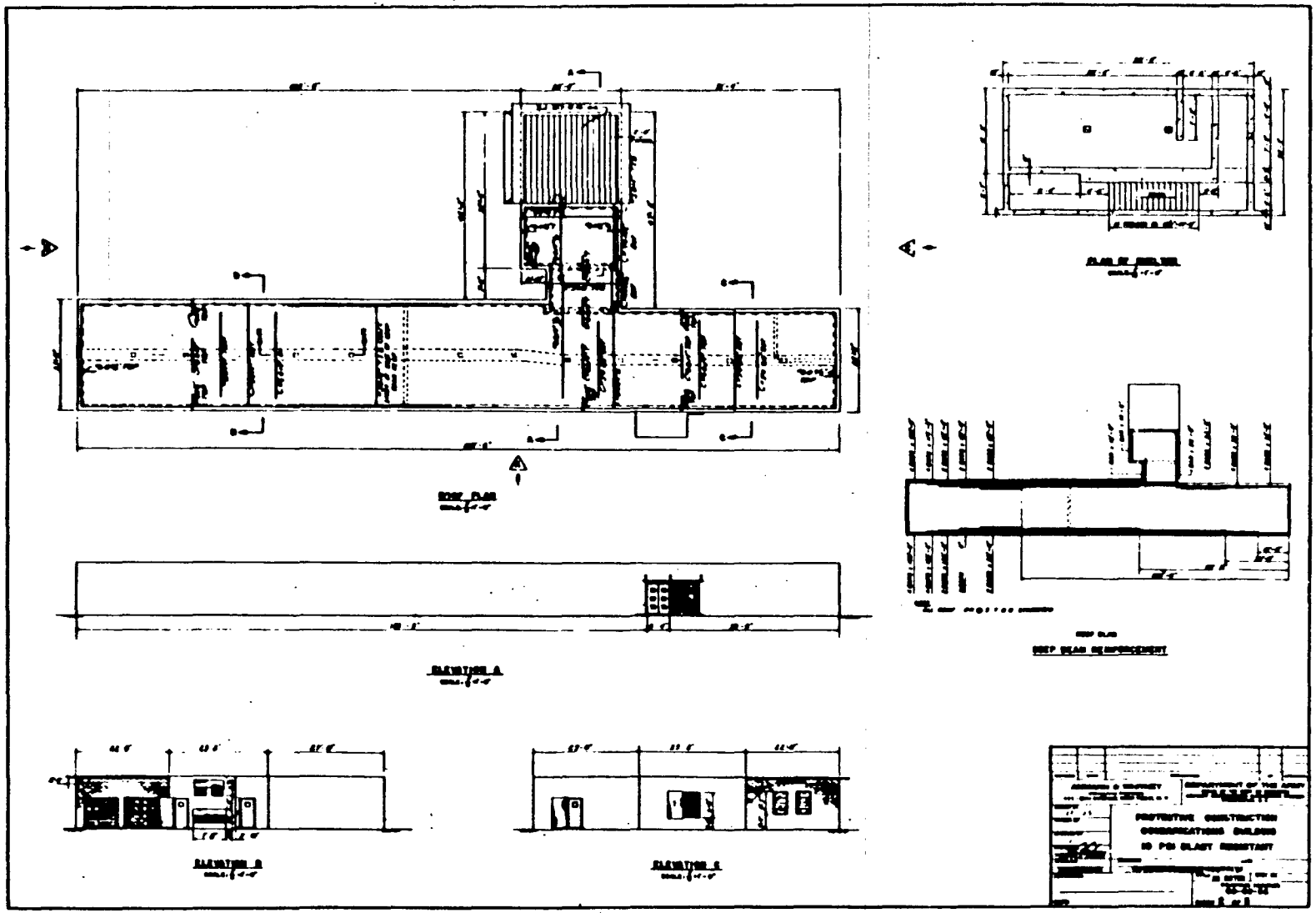


Fig. 2.4

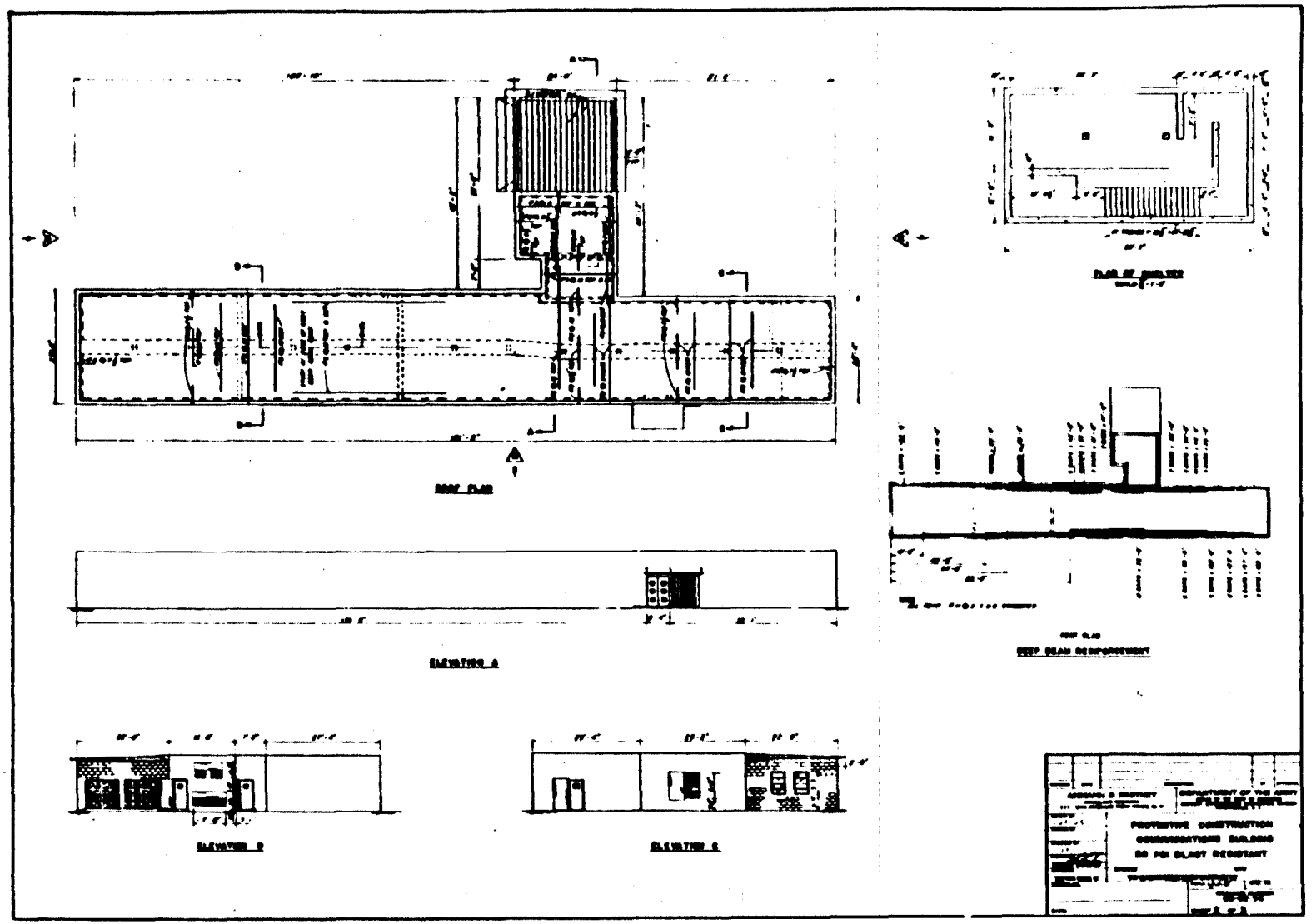


Fig. 2.5

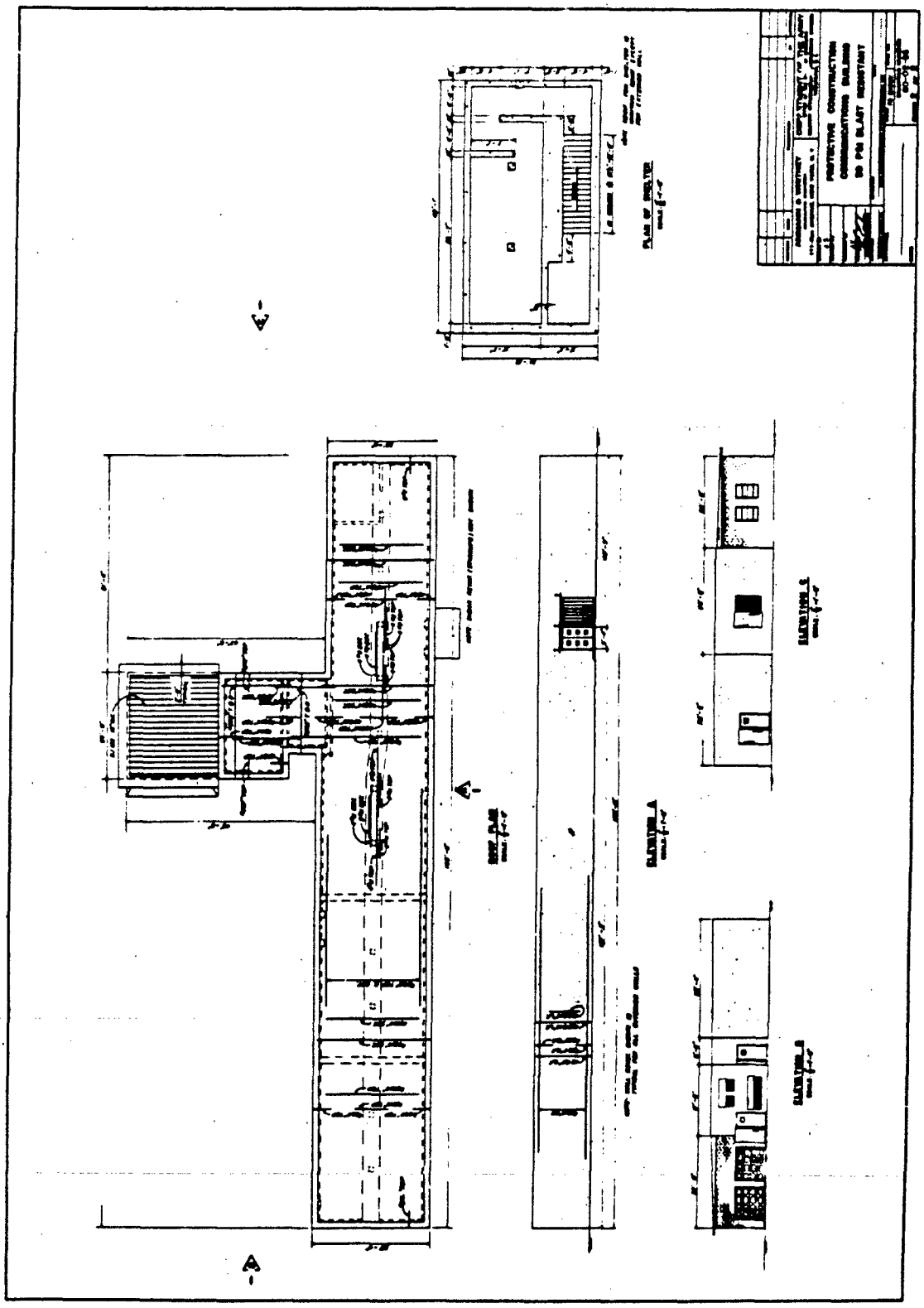


Fig. 2.6

The wall panels of the main wing are designed as one way slabs supported at the roof and floor slabs. The roof and floor slabs are designed as deep beams to carry the wall panel blast loads. The concrete walls are utilized as shear wa walls to transmit the translational loads from the roof and floor slabs to the foundation. It was necessary to add an interior shear wall in the Terminal Room for the 30 psi level design.

A buried personnel shelter, for radiation and fallout protection, with a capacity of approximately 30 persons (based upon 10 sq. ft. of floor area per person) is provided below the Switchboard Room. Concrete thicknesses in the shelter is controlled by the radiation requirements.

The roof, walls, columns and footings are designed for plastic deformations. Blast doors are designed for maximum elastic deformation.

2.3 ITEM NO. 3 - BASE SUPPLY WAREHOUSE (10, 20, 30 PSI)

2.3.1 General

The design of the Base Supply Warehouse as shown on Ammann & Whitney Drawings No. 60-17-01 is adapted from the following drawings entitled "Keesler Air Force Base, Mississippi, Base Supply Warehouse, Corps of Engineers, U.S. Army, Office of the District Engineer, Mobile, Alabama (October 8, 1953)".

Drawing No.		File No.
16-06-13	sheet 1 of 1	BIL - 1803
33-02-02	" 1 of 5	" - 1804
"	" 2 of 5	" - 1805
"	" 3 of 5	" - 1806
"	" 4 of 5	" - 1807
"	" 5 of 5	" - 1808
71-03-10	" 1 of 1	" - 1809

2.3.2 Existing Building

The interior dimensions of the Keesler AFB warehouse (Warehouse "F") are 62'-4" x 237'-4". The walls are concrete block. Roof joists span 21'-0" between longitudinal concrete beams which are supported by concrete columns 14'-0" on centers. The roof system as shown on the above drawings, may be either precast concrete joists or bar joists. The vertical clearance to the longitudinal concrete beams carrying the joists is 12'-8" for the precast system and 13'-9" for the bar joists system. The floor slab rests on fill and is 4'-0" above grade. The existing building is divided into two areas by a 12" brick fire wall.

2.3.3 Blast Resistant Design (Fig. 1.7 - 1.9)

The proposed Blast Resistant Warehouse is a reinforced concrete, windowless structure with both utility and blast doors for all openings. The clear dimensions have been maintained essentially the same as those of the Keesler AFB structure. The minimum vertical clearance (12'-8" to bottom of transverse beams) is the same as used at Keesler AFB.

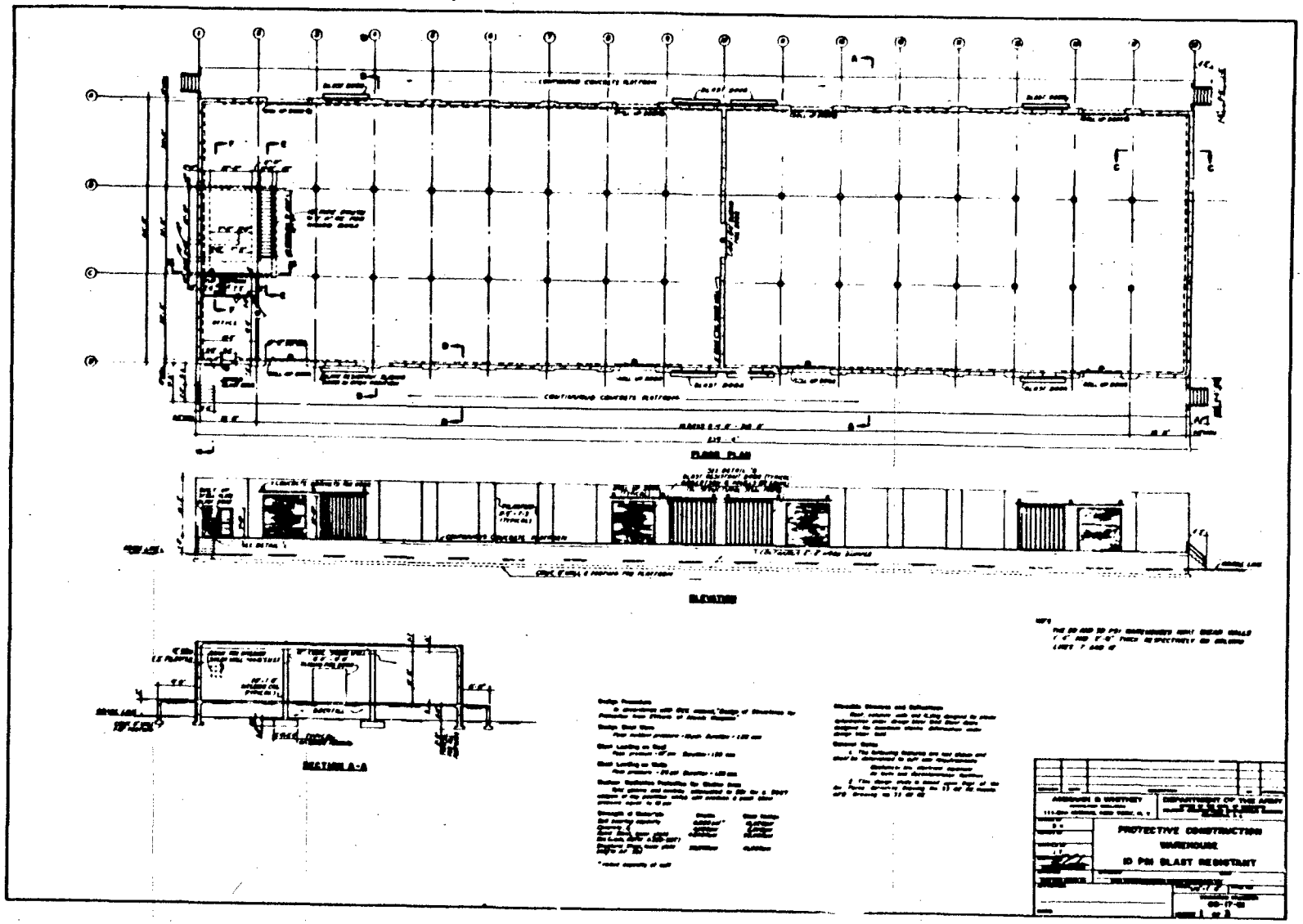

PROTECTIVE CONSTRUCTION
WAREHOUSE
10 PSI BLAST RESISTANT

Fig. 2.7

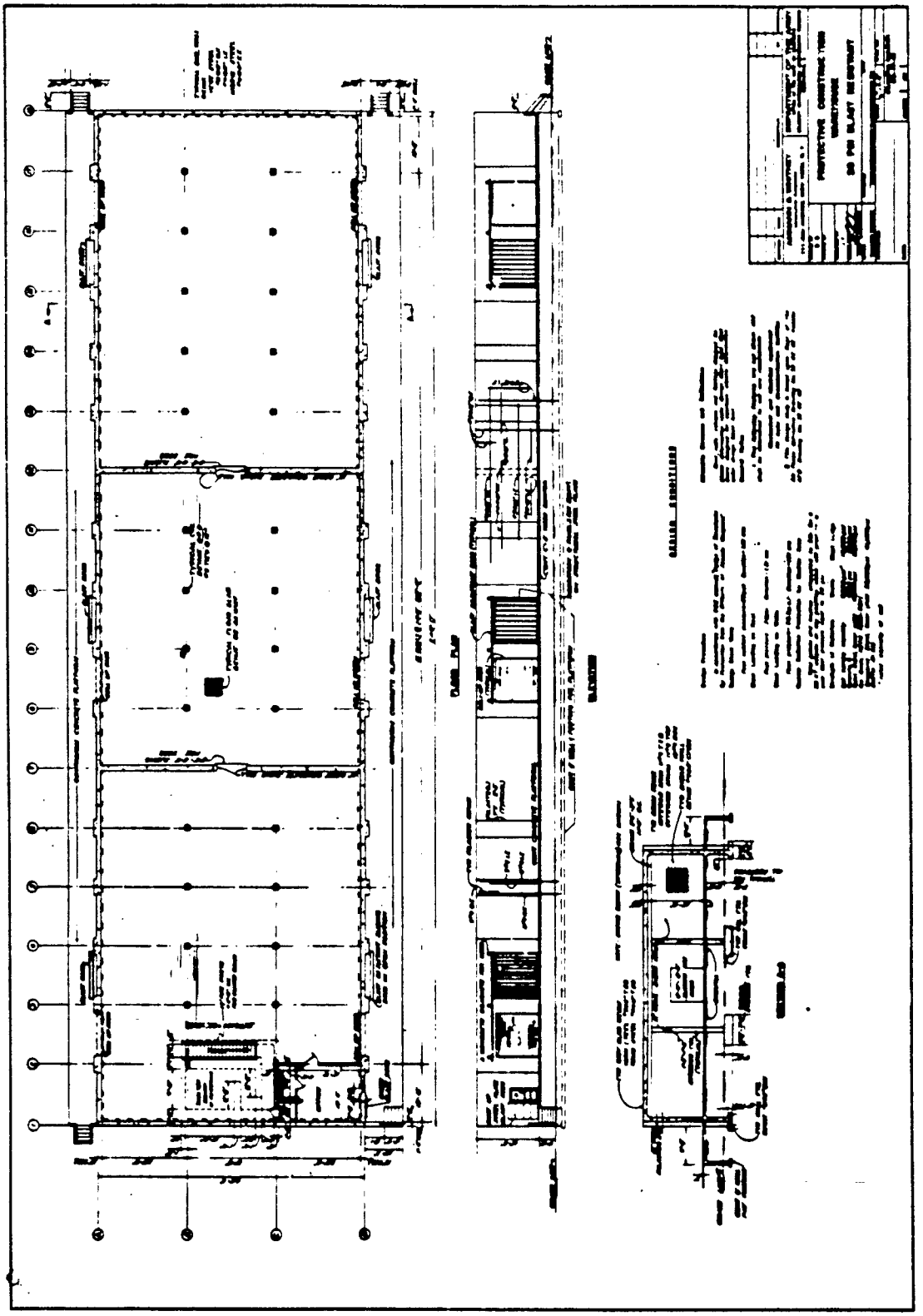


Fig. 2.8

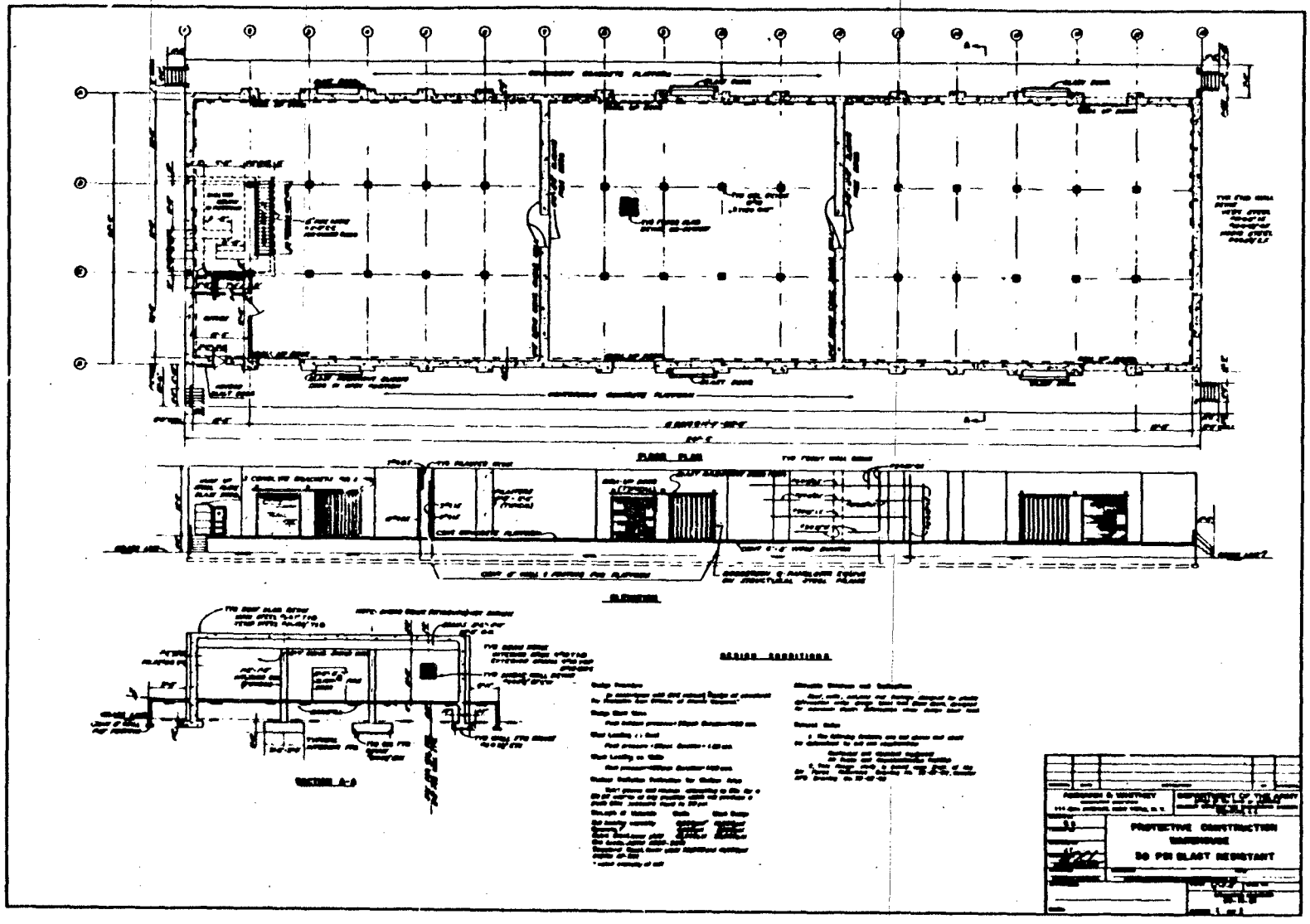

PROTECTIVE CONSTRUCTION
WAREHOUSE
50 PSI BLAST RESISTANT

Fig. 2.9

The roof is of beam and slab construction, utilizing shallow beams to minimize the overall building height and the vertical span of the walls. The roof beams are restrained at the walls by pilasters of the same cross sectional dimensions as the beams. The front and rear wall panels are designed as two-way slabs supported at the pilasters and the floor and roof slabs. The end walls span vertically between the roof and floor slabs. The roof and floor slabs are designed as deep beams to carry the wall panel blast loads. The concrete walls are utilized as shear walls to transmit the translational loads from the roof and floor slabs to the foundation. One interior shear wall (at column line 10) was used for the 10 and 20 psi designs, and two interior shear walls (at column lines 7 and 12) were used for the 30 psi design.

A buried personnel shelter, for radiation and fallout protection, with a capacity of approximately 10 persons (based upon 10 sq. ft. of floor area per person) is provided below the floor slab adjacent to the office area. The concrete thicknesses in the shelter area is controlled by the radiation requirements.

The roof, walls, columns and footings are designed for plastic deformation. Blast doors are designed for maximum elastic deformation.

2.4 ITEM NO. 4 - EARTH COVERED CONCRETE IGLOO MAGAZINES (25, 50, 100, 200 PSI)

2.4.1 General

The design of the earth covered concrete Igloo as shown on Ammann & Whitney Drawing No. 60-17-02 is adapted from drawing No. 33-15-06, Sheet 1 to 7 of 7 sheets, entitled "Magazine, Mounted Concrete Igloo, "Department of the Army, Office of the Chief of Engineers, Military Construction Engineering Division, Washington, D.C. (1 August 1951).

2.4.2 Existing Building

The interior floor dimensions of the existing building are 60'-8" x 26'-6". The arch thickness varies from 6" at the crown to 1'-4" at the floor level. The arch is tied by tie beams beneath the floor slab. The floor slab which is on a 6" gravel fill, is 2'-1" to 4'-6" above the 6'-0" wide footings. Access to the building is by way of double steel doors at the end wall. Above the crown, the arch is covered with 2'-0" of earth which slopes to grade around the perimeter.

2.4.3 Blast Resistant Design (Fig. 1.10 - 1.13)

The proposed structures is a reinforced concrete arch with the same interior floor dimensions as the existing type structure. The distance between the top of the floor slab and the arch intrados at the crown 12'-9" (intrados radius = 13'-5"). The top of the floor slab is at grade. The arch thicknesses are 8, 14, 22 and 28 inches for the 25, 50, 100

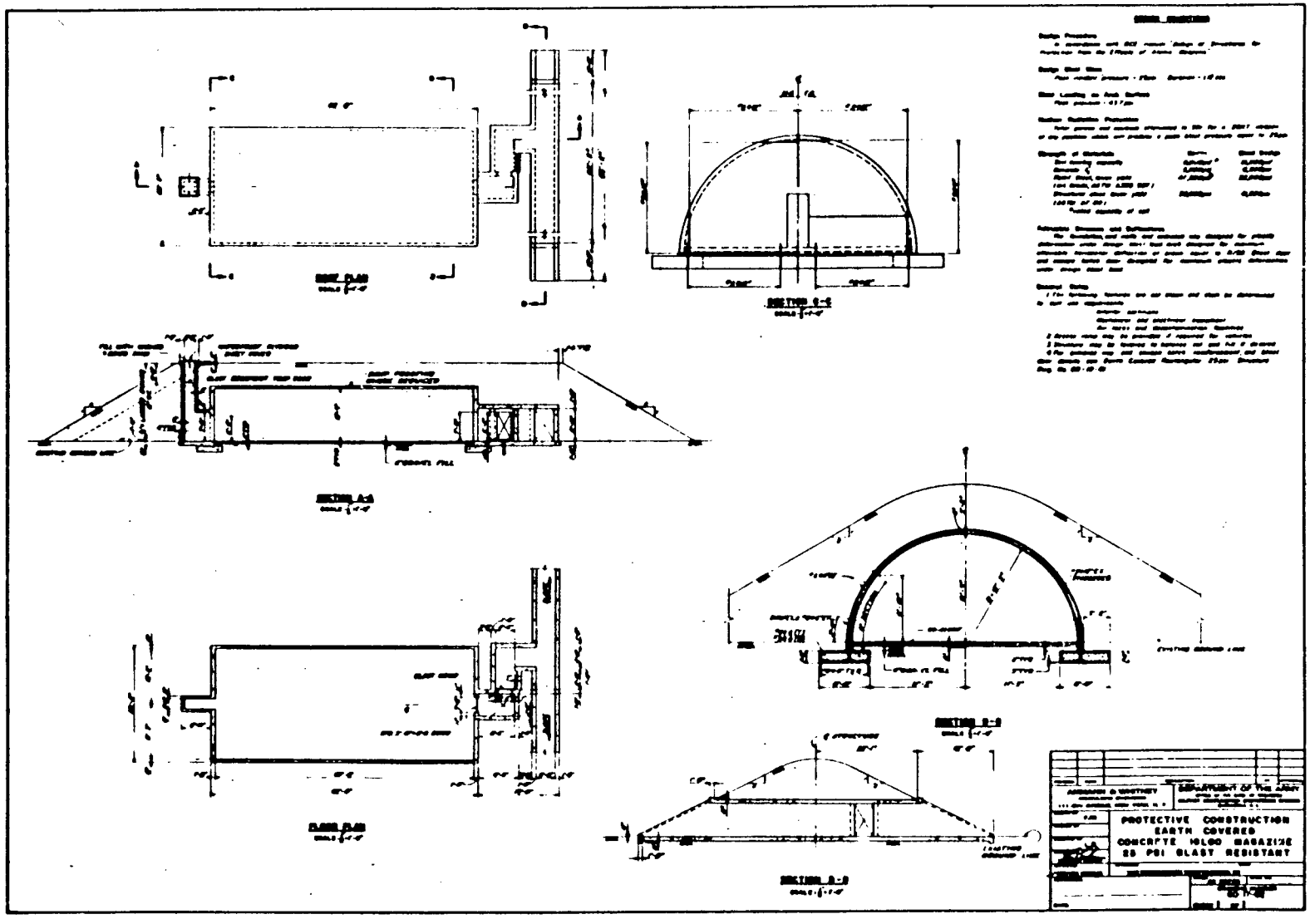

PROTECTIVE CONSTRUCTION
EARTH COVERED
CONCRETE 1010D MAGAZINE
25 PSI BLAST RESISTANT

Fig. 2.10

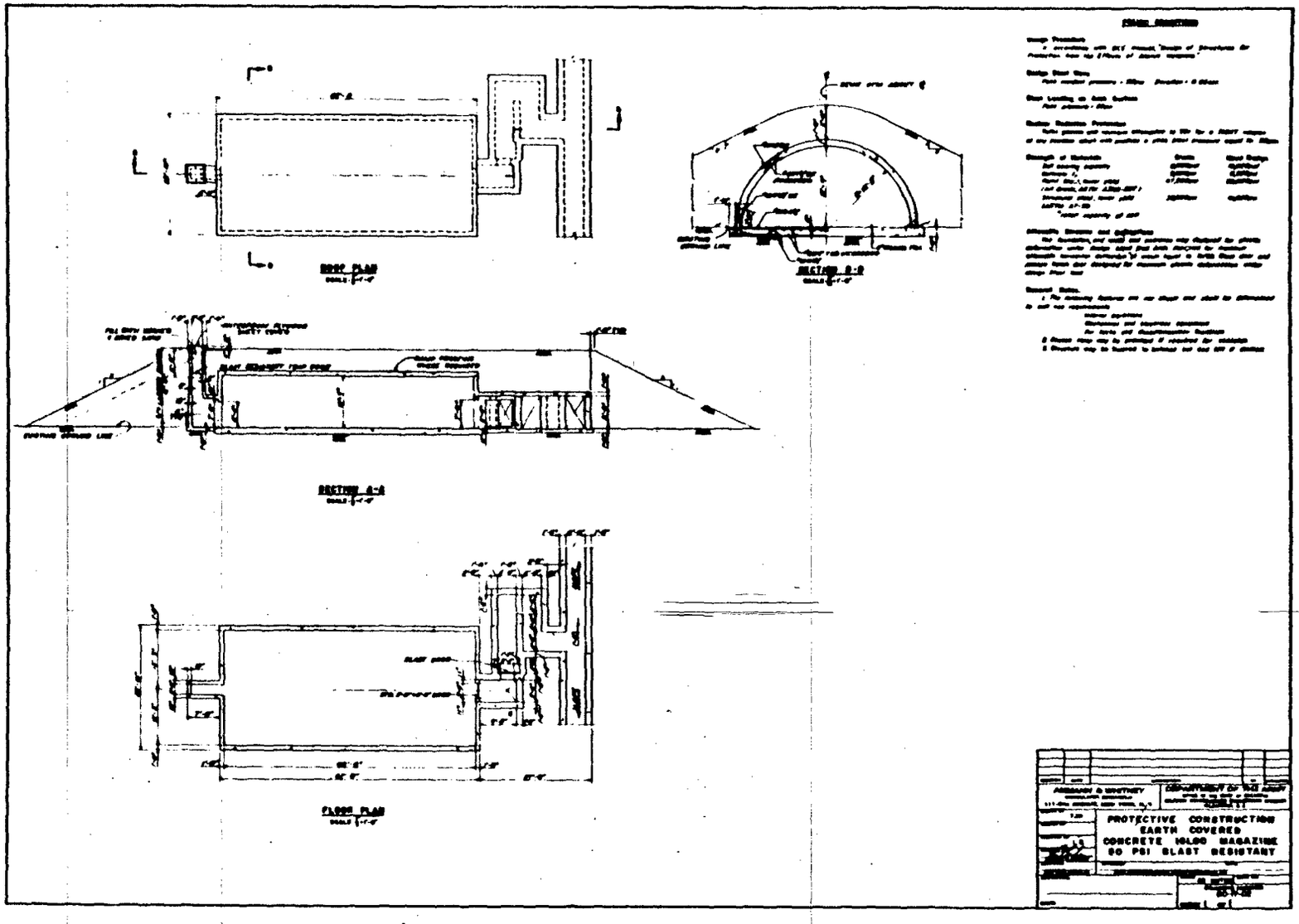

PROTECTIVE CONSTRUCTION
EARTH COVERED
CONCRETE IGLOO MAGAZINE
50 PSI BLAST RESISTANT

Fig. 2.11

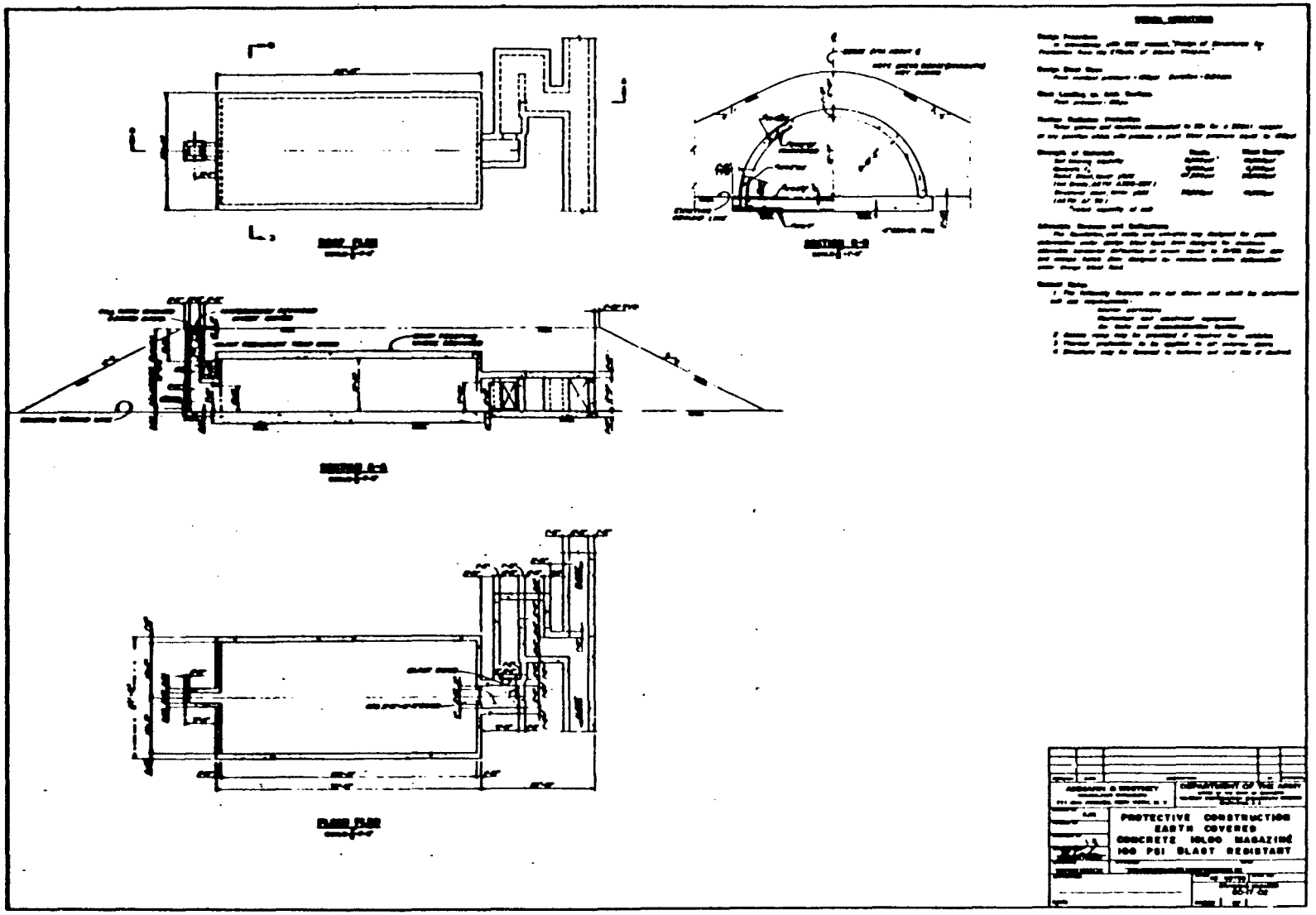

PROTECTIVE CONSTRUCTION
EARTH COVERED
CONCRETE MAGAZINE
100 PSI BLAST RESISTANT

Fig. 2.12

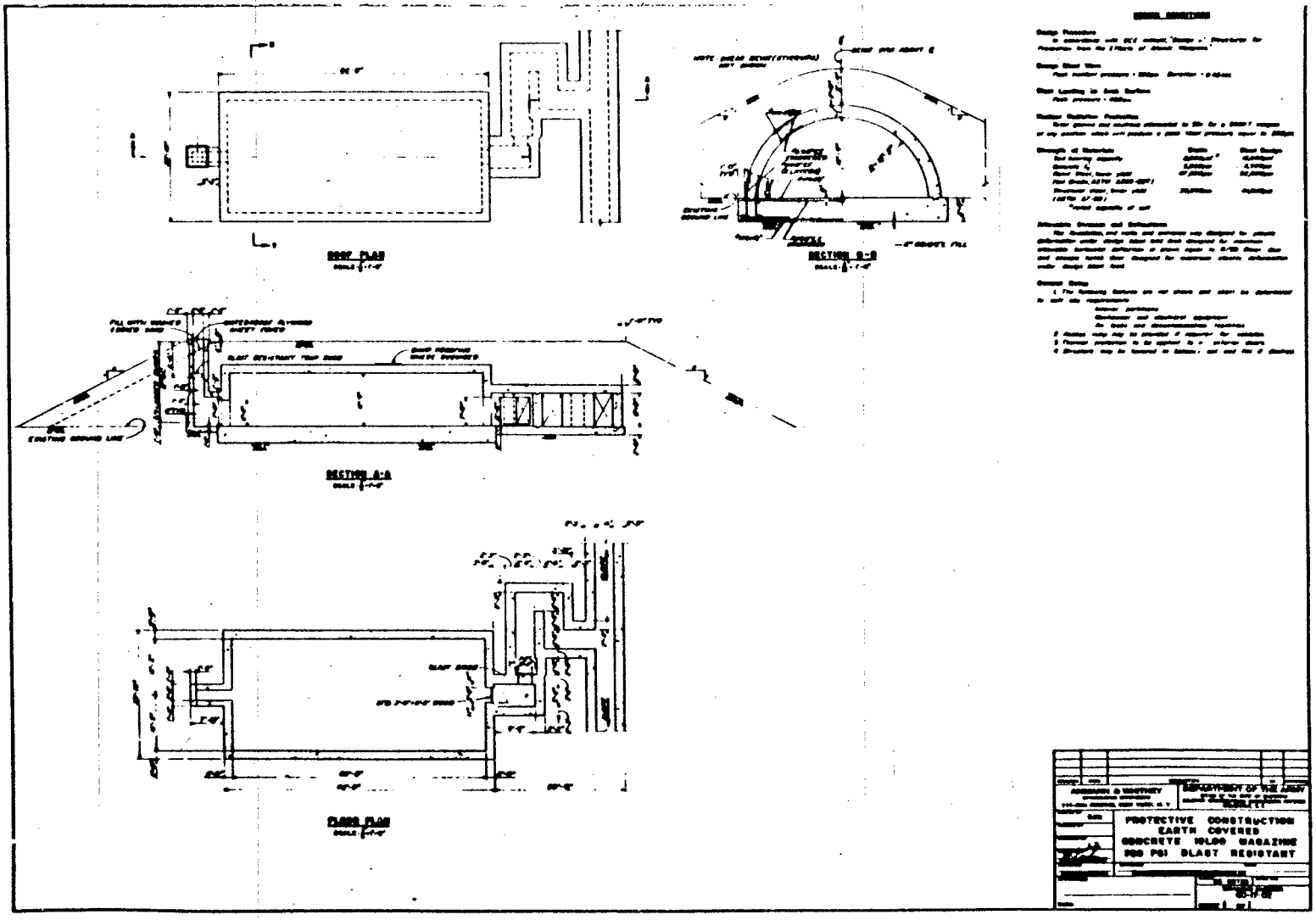

PROTECTIVE CONSTRUCTION
EARTH COVERED
CONCRETE IGLOO MAGAZINE
200 PSI BLAST RESISTANT

Fig. 2.13

and 200 psi pressure levels respectively. The arch is covered with earth, as required for radiation protection, and may be lowered if it is desired to balance cut and fill. Entrance to the structure is by way of a T-shaped (in plan) corridor through the earth cover. The entry is baffled for radiation requirements. A steel blast resistant door at the corridor, a conventional door for ordinary use and an emergency exit are provided as shown on the drawings. The foundation, end walls and entranceway are designed for plastic deformation. The arch is designed for a maximum side sway at the crown equal to 1/50 of the radius. The blast door and escape hatch door are designed for maximum elastic deformation.

The blast load over the entire section of the arch was assumed as a uniform radial pressure plus an antisymmetrical radial pressure as recommended in the C of E Manual. The blast load on the surface of the earth cover for the 50, 100 and 200 psi levels was computed by the method described in "Transonic Pressures on Above-Ground Earth Covered Structures", Appendix B. The 25 psi level loading was computed in accordance with the C of E Manual. The pressure on the surface of the structure was then computed by use of the "Mohr's Circle Solution".

2.5 ITEM NO. 5 - EARTH COVERED CONCRETE RECTANGULAR STRUCTURE (25, 50, 100, 200 PSI)

2.5.1 General

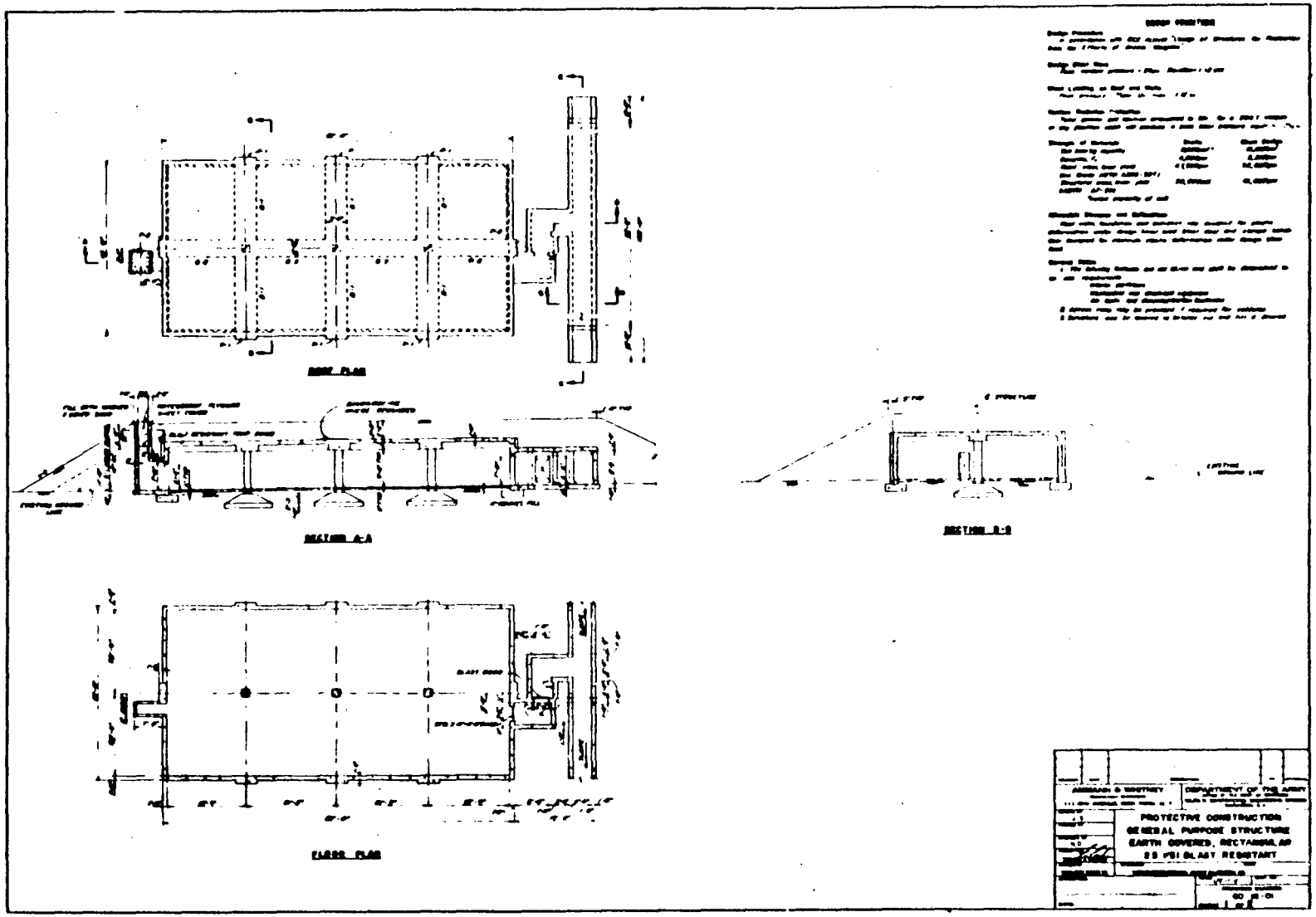
The design of the Earth-Covered, Concrete Rectangular Structure as shown on Ammann & Whitney Drawing No. 60-18-01

conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.5.2 Blast Resistant Design (Fig. 1.14 - 1.17)

The proposed structure is a reinforced concrete rectangular box with floor dimensions of 40'-0" x 80'-0" clear. The minimum vertical clearance is 9'-0" to bottom of beams. The top of the floor slab is at grade. The structure is covered with earth, as required for radiation protection, of constant depth above the roof and with a 2:1 slope around the perimeter. The structure may be lowered if it is desired to balance cut and fill. Entrance to the structure is by way of a T-shaped (in plan) corridor through the earth cover. The entry is baffled for radiation requirements. A steel blast resistant door at the corridor, a conventional door for ordinary use and an emergency exit are provided as shown on the drawings. The roof is of beam and slab construction, with shallow interior beams to minimize the overall building height and the vertical span of the walls. The roof beams are restrained at the walls by exterior pilasters. The wall panels are two-way slabs supported at the pilasters, roof slab and floor slab.

The roof, walls, foundation and entranceway are designed for plastic deformation. The blast door and escape hatch door are designed for maximum elastic deformation.


ROOF PLAN
SECTION A-A
SECTION B-B
FLOOR PLAN
PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
EARTH COVERED, RECTANGULAR
20 PSI BLAST RESISTANT

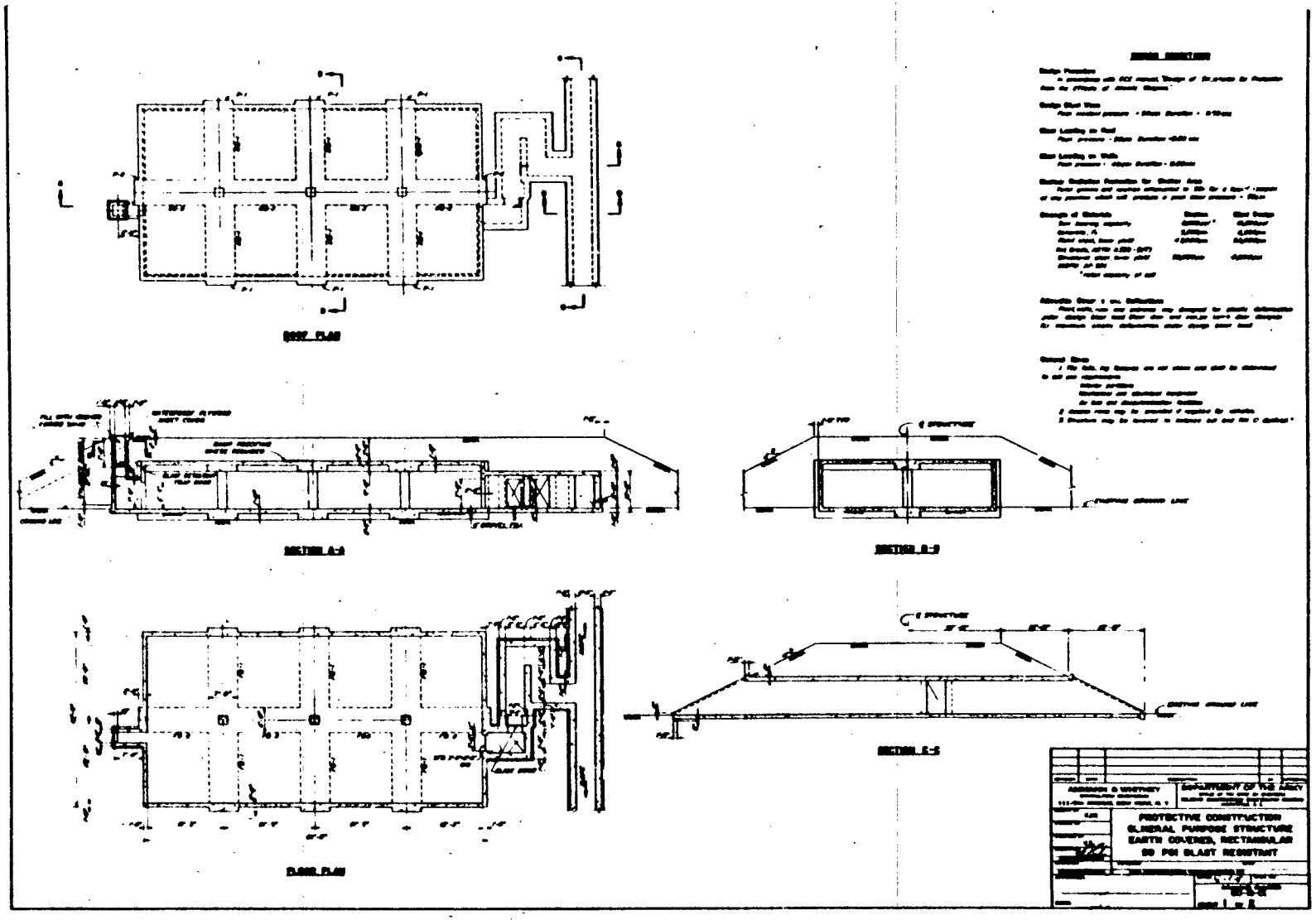

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
EARTH COVERED, RECTANGULAR
50 PSI BLAST RESISTANT

Fig. 2.15

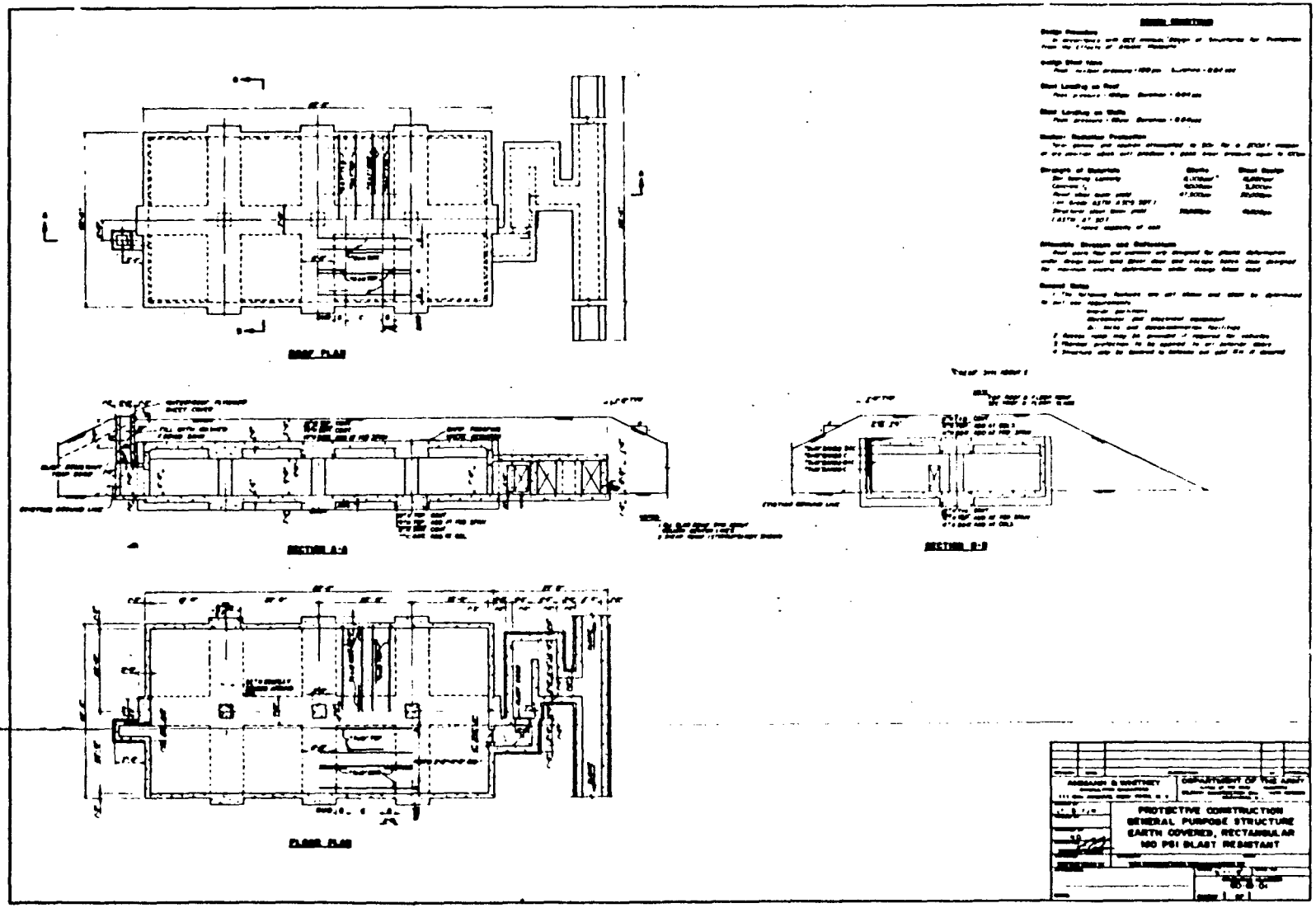

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
EARTH COVERED, RECTANGULAR
100 PSI BLAST RESISTANT

Fig. 2.16

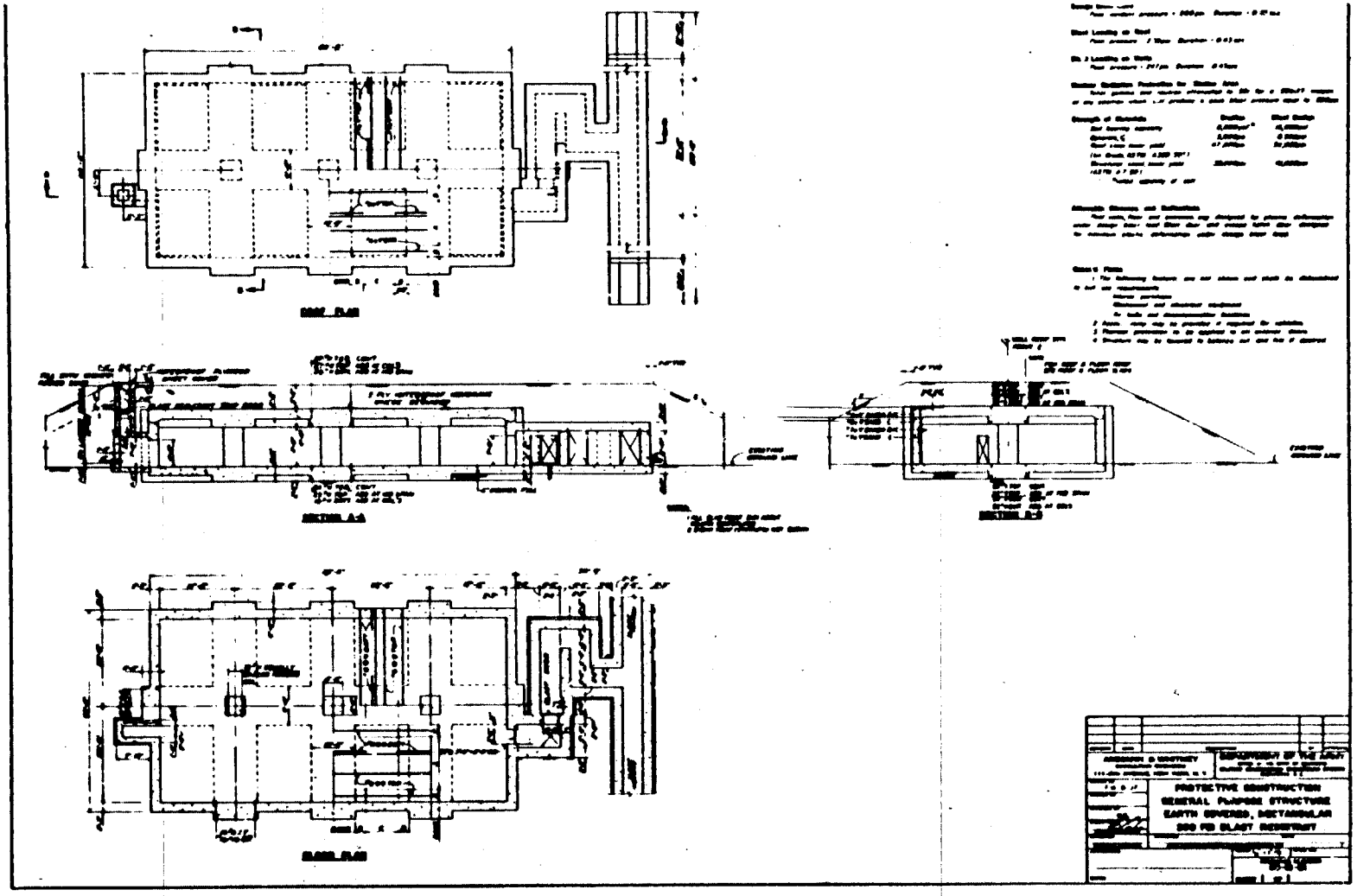


Fig. 2.17

The blast load on the surface of the earth cover was computed by the method described in "Transonic Pressures on Above Ground Earth Covered Structures", Appendix 3. The pressure on the structure was then computed by use of the "Mohr's Circle Solution".

2.6 ITEM NO. 6 - EARTH COVERED, CONCRETE DOUBLE BARREL ARCH (50 PSI)

2.6.1 General

The design of the Earth Covered Concrete Double Barrel Arch as shown on Ammann & Whitney Drawings No. 16-18-02 conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.6.2 Blast Resistant Design (Fig. 1.18)

The proposed structure is a reinforced concrete double barrel arch with interior floor dimensions of 80'-0" x 44'-0". The distance between the top of the floor slab and the intrados at the crown is 12'-6", (intrados radius = 12'-0"). The top of the floor slab is at grade. The arches, which are 12" thick, are supported along their intersection by a common wall. The clear distance between the top of the floor slab and the intrados along the longitudinal centerline is 7'-0". The structure is covered with earth, as required for radiation protection, with a depth of 5'-6" above the crown and 2:1 slopes around the perimeter. The structure may be lowered if it is desired to balance cut and fill. Entrance to the structure is by way

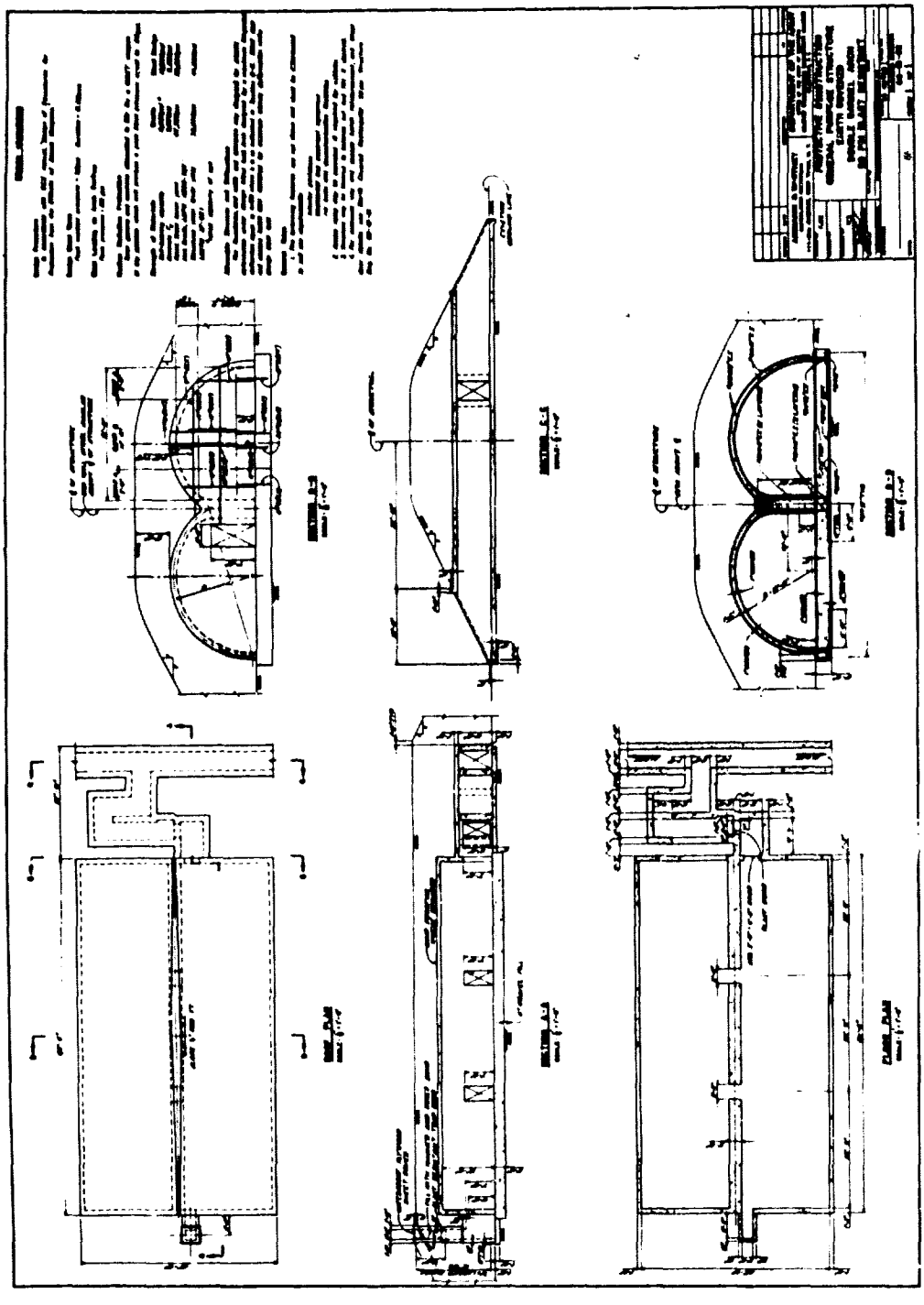


Fig. 2.18

of a T-shaped (in plan) corridor through the earth cover. The entry is baffled for radiation requirements. A steel blast resistant door at the corridor, a conventional door for ordinary use and an emergency exit are provided as shown on the drawings

The foundation, end walls and entranceway are designed for plastic deformation. The arches were analyzed as a system with fixed exterior supports and a common elastic support at the interior wall. Each of the arches is designed for a maximum allowable sidesway 1/100 of the springing line cord length. The blast door and escape hatch door were designed for maximum elastic deformation.

The blast load on the surface of the earth cover was computed by the method described in "Transonic Pressure on Above Ground Earth Covered Structures" Appendix B. The pressure on the structure was then computed by use of the "Mohr's Circle Solution".

The blast load on each arch was assumed as a uniform radial pressure plus an antisymmetrical radial pressure as recommended in the C of E Manual.

2.7 ITEM NO. 7 - EARTH COVERED CONCRETE DOME (50, 100, 200 PSI)

2.7.1 General

The design of the Earth Covered Concrete Dome as shown on Ammann & Whitney Drawing No. 60-18-03 conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.7.2 Blast Resistant Design (Fig. 1.19 - 1.21)

The proposed structure is a reinforced concrete hemispherical dome with a constant inside radius of 12'-6" and an inside diameter at the floor of 25'-0". The top of the floor slab is on grade. The structure is covered with earth, as required for radiation protection, and may be lowered if it is desired to balance cut and fill. Entrance to the structure is by way of a T-shaped (in plan) corridor through the earth cover. The entry is baffled for radiation requirements. A steel blast resistant door at the corridor, a conventional door for ordinary use and an emergency exit are provided as shown on the drawings.

The foundation and entranceway are designed for plastic deformation. The dome, blast door, and escape hatch door are designed for maximum elastic deformation.

The blast load on the surface of the earth cover was computed by the conservative assumption that the floor was two dimensional and using the method described in "Transonic Pressures on Above Ground Earth Covered Structures", Appendix B. The pressure on the structure was then computed by use of the "Mohr's Circle Solution". The blast load over the dome surface was assumed as a uniform radial pressure plus an antisymmetrical radial pressure as recommended in the C of E Manual.

2.8 ITEM NO. 8 - BURIED CONCRETE RECTANGULAR (50, 100, 200 PSI)

2.8.1 General

The design of the Buried Rectangular Structure as shown

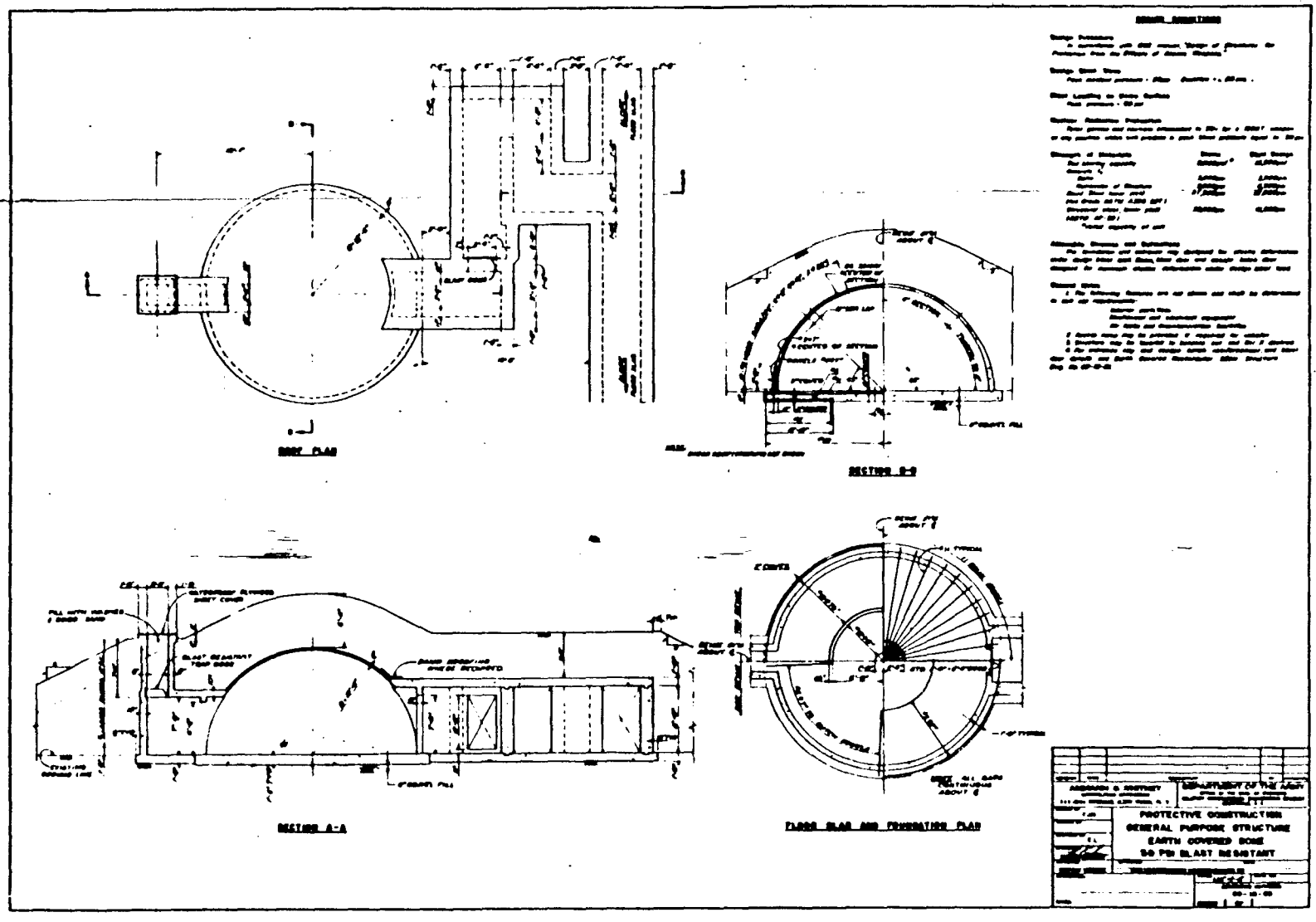

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
EARTH COVERED DOME
50 PSI BLAST RESISTANT

Fig. 2.19

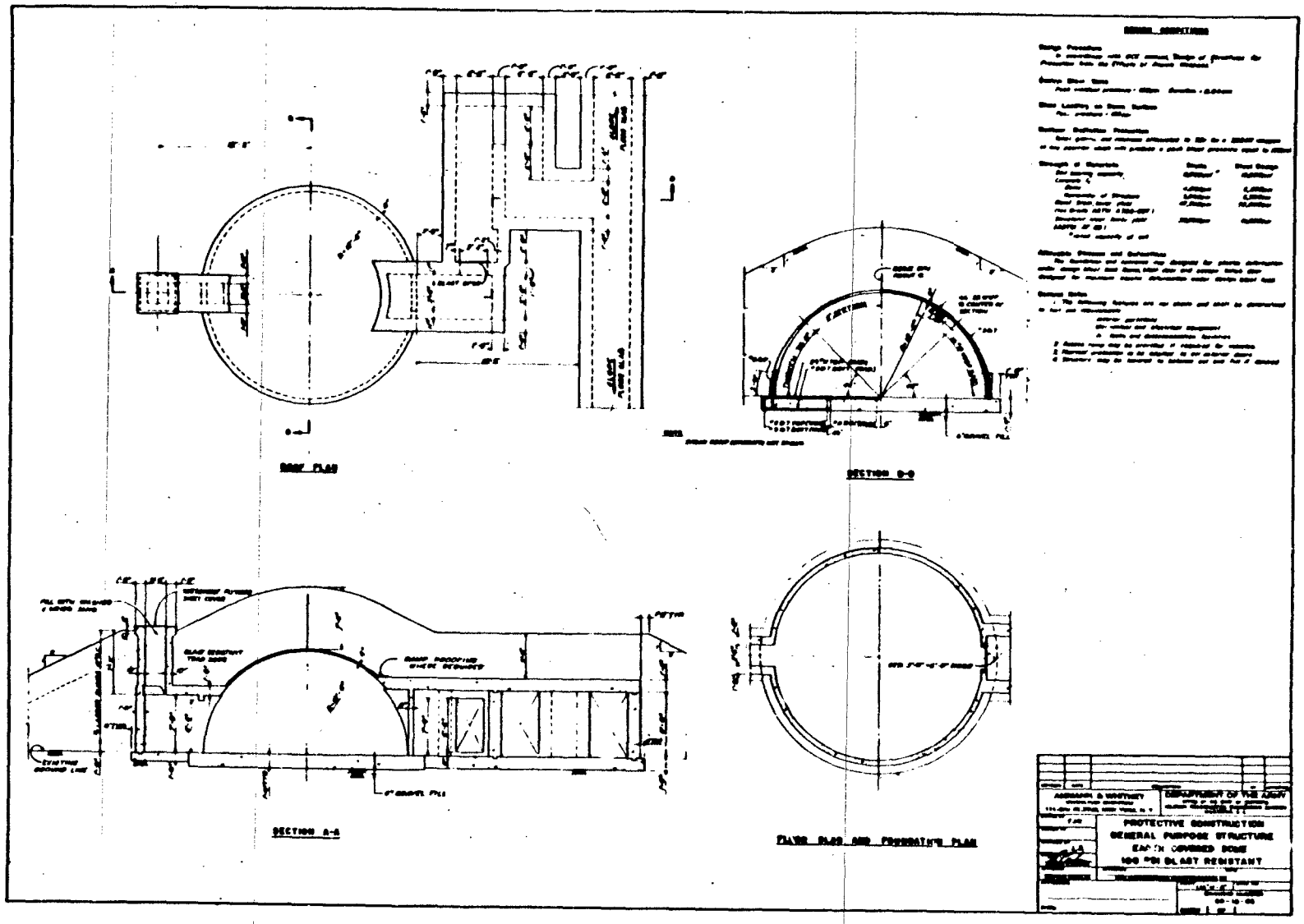

SECTION B-B
SECTION A-A
PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
EARTH COVERED DOME

Fig. 2.20

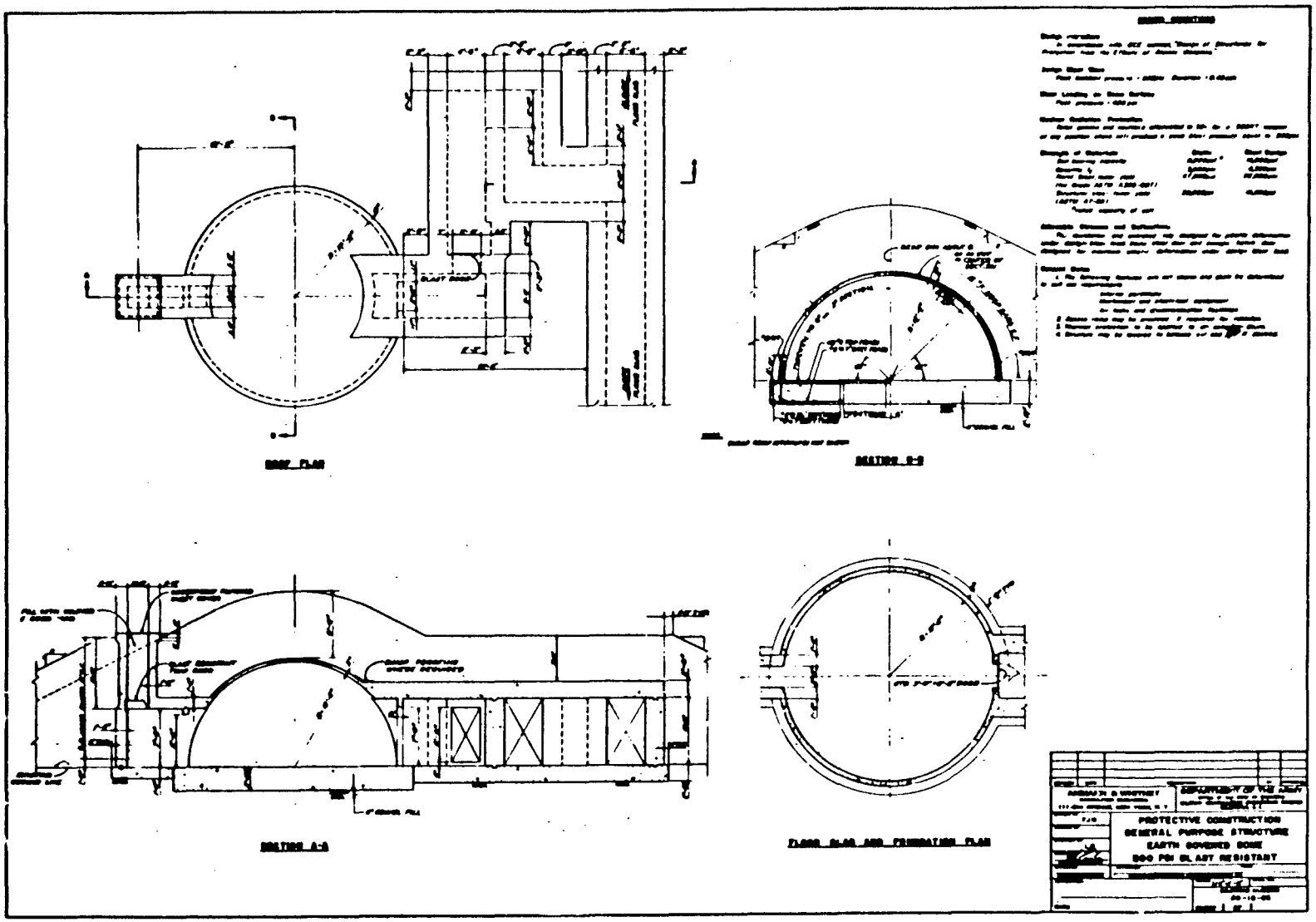

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
EARTH COVERED DOME
200 PSI BLAST RESISTANT

Fig. 2.21

on Ammann & Whitney Drawing No. 60-18-04 conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.8.2 Blast Resistant Design (Fig. 1.22 - 1.24)

The proposed structure is a reinforced concrete rectangular box with floor dimensions of 40'-6" x 80'-0" clear. The minimum vertical clearance is 9'-0" to bottom of beams. The structure is located below grade as required for radiation protection. The entrance consists of a partially covered stairwell which is separated from the main structure by means of a steel blast resistant door. A conventional door for ordinary use and an emergency exit are provided as shown on the drawing. The roof is of beam and slab construction, with shallow interior beams to minimize the overall building height and the vertical span of the walls. The roof beams are restrained at the walls by interior pilasters of the same cross sectional dimensions as the beams. The wall panels are two-way slabs supported at the pilasters, roof slab and floor slab.

The roof, walls, foundation and entranceway are designed for plastic deformation. The blast door and escape hatch door are designed for maximum elastic deformation.

The blast load on the roof slab and walls of the main structure was assumed to be the same as the incident pressure at the ground surface.

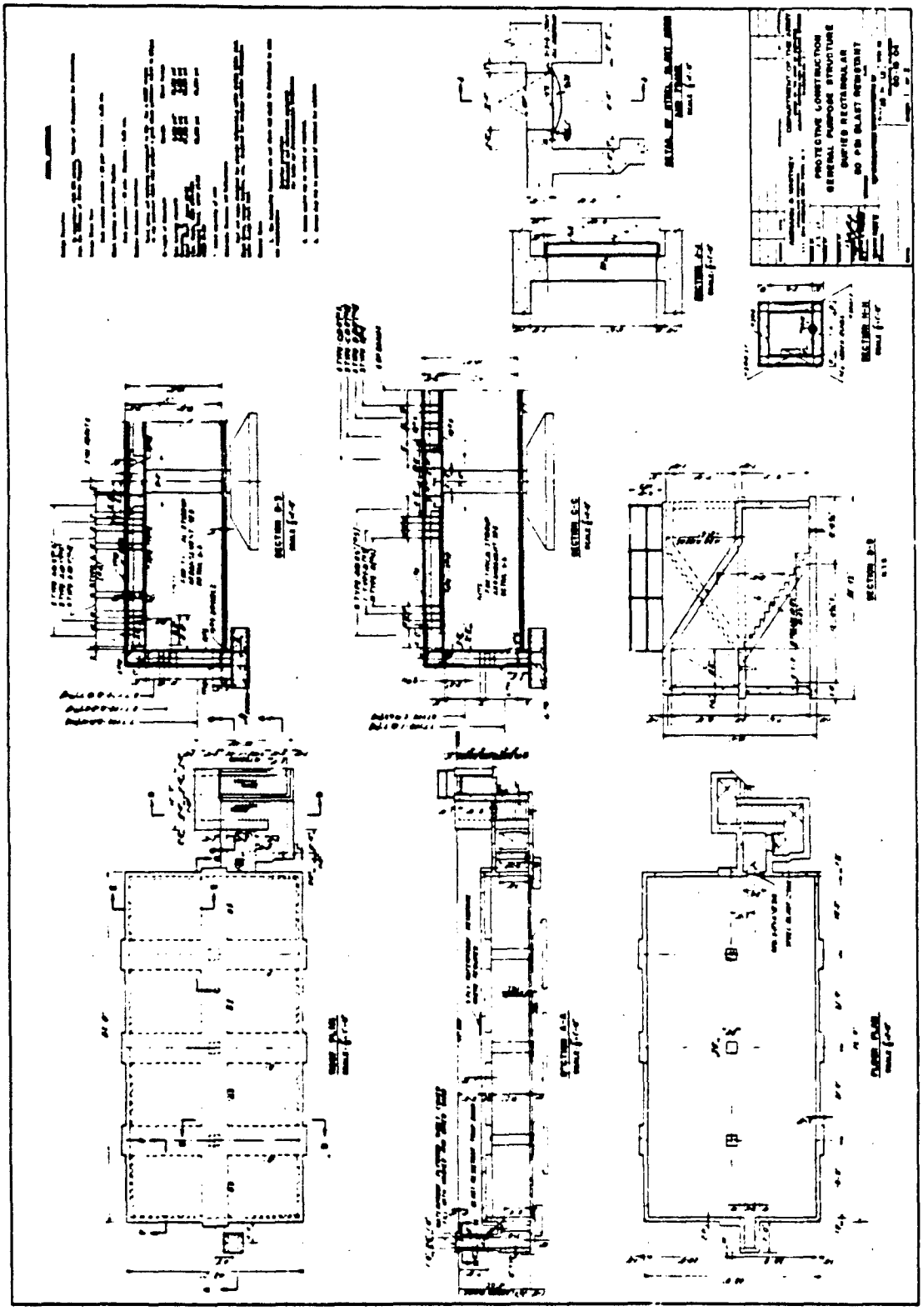


Fig. 2.22

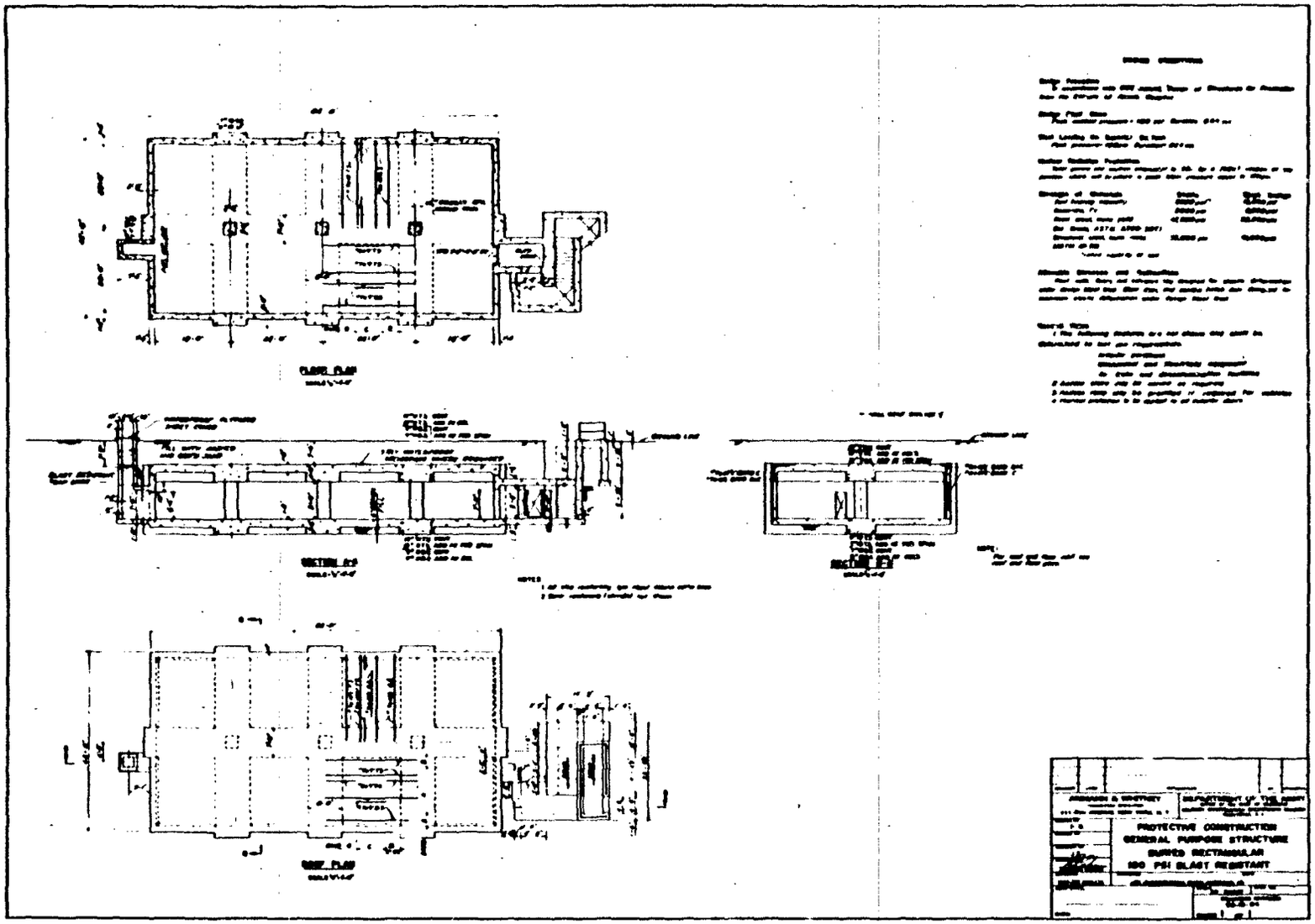

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
BURIED RECTANGULAR
100 PSI BLAST RESISTANT

Fig. 2.23

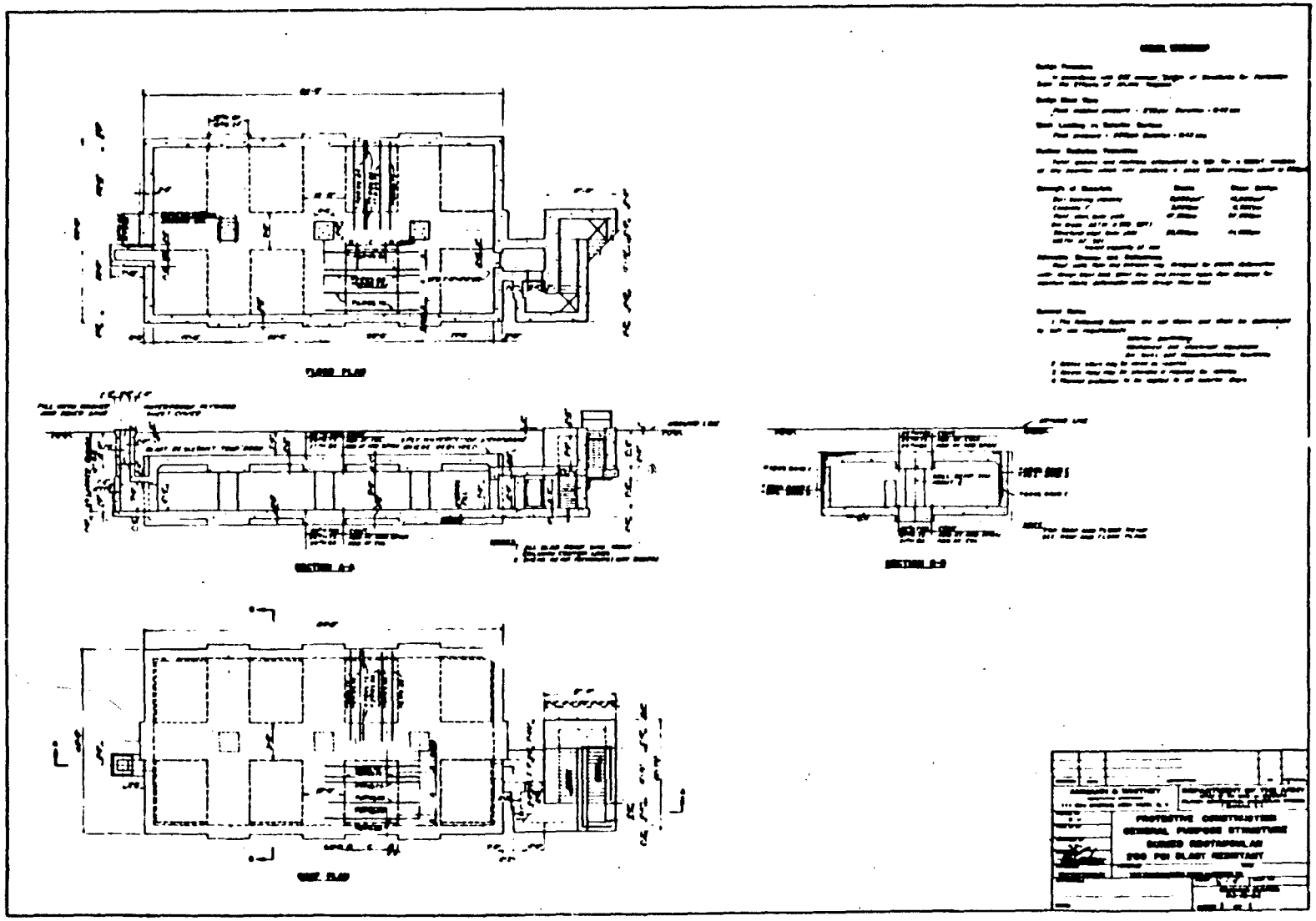


Fig. 2.24

2.9 ITEM NO. 9 - BURIED CONCRETE DOUBLE BARREL ARCH (50 PSI)

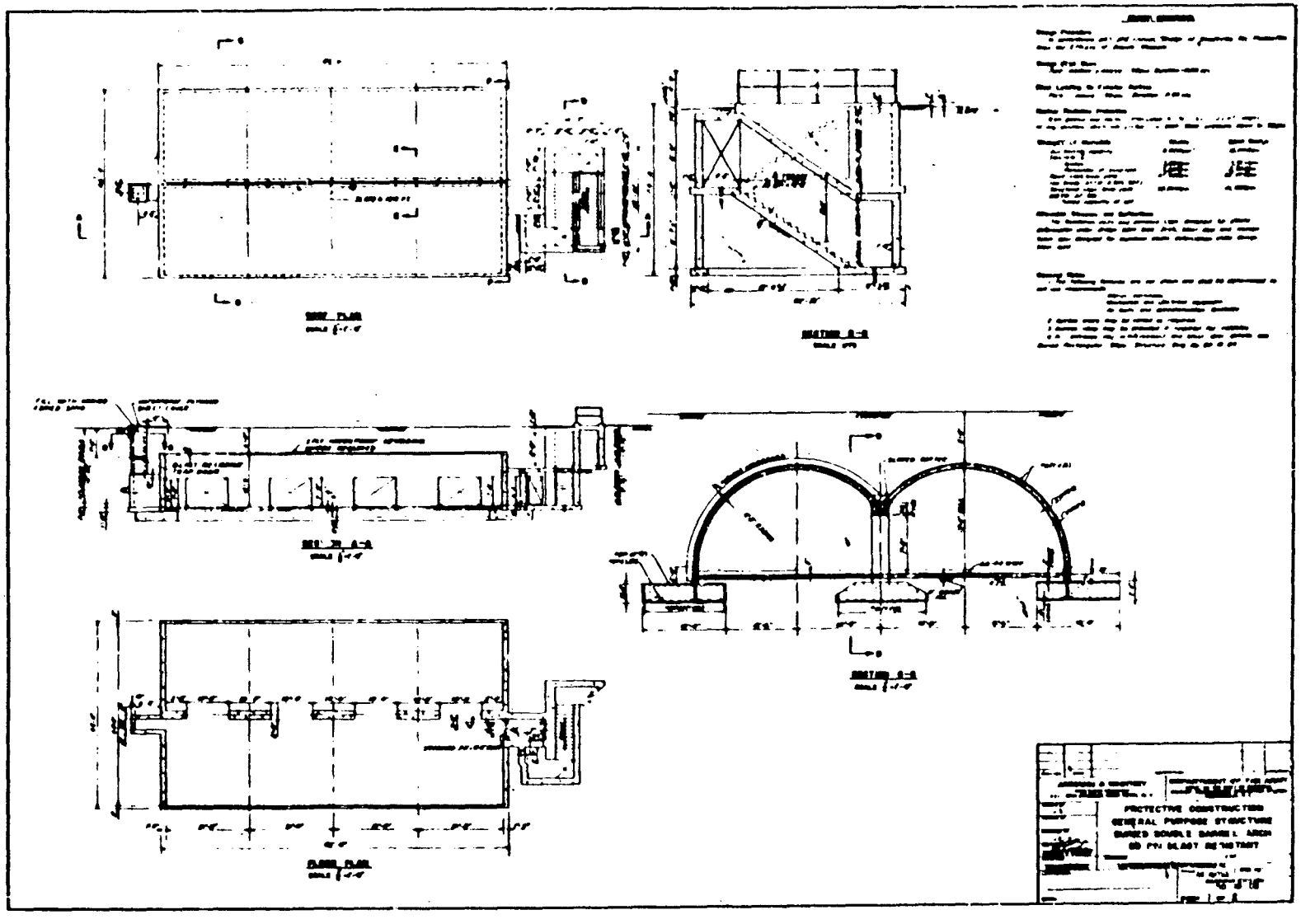
2.9.1 General

The design of the Buried Concrete Double Barrel arch as shown on Ammann & Whitney Drawing No. 60-18-05 conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.9.2 Blast Resistant Design (Fig. 1.25)

The proposed structure is a reinforced concrete double barrel arch and has interior floor dimensions of 80'-0" x 44'-0". The distance between the top of the floor slab and the intrados at the crown is 12'-6" (intrados radius = 12'-0"). The arches, which are 8" thick, are supported along their intersection by a common wall. The clear distance between the top of the floor slab and the intrados along the longitudinal centerline is 7'-0". The extrados at the crown is 6'-0" below the ground level as required for radiation protection. The entrance consists of a partially covered stairwell which is separated from the main structure by means of a blast resistant steel door. A conventional door for ordinary use and an emergency exit are shown on the drawing.

The roof, walls, floor and entranceway were designed for plastic deformation. The blast door and escape hatch door were designed for maximum elastic deformation.



PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
BURIED DOUBLE BARREL ARCH
60 PSI BLAST RESTRAINT

The blast load on each arch was assumed as a uniform radial pressure equal to the incident pressure at the ground surface as recommended in the C of E Manual.

2.10 ITEM NO. 10 - BURIED CONCRETE DOME (50, 100, 200 PSI)

2.10.1 General

The design of the Buried Concrete Dome as shown on Ammann & Whitney Drawing No. 60-18-06 conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.10.2 Blast Resistant Design

The proposed structure is a reinforced concrete hemispherical dome with a constant inside radius of 12'-6" and an inside diameter at the floor of 25'-0". The structure is below grade as required for radiation protection. The entrance consists of a partially covered stairwell which is separated from the main structure by means of a blast resistant steel door. A conventional door for ordinary use and an emergency exit are shown on the drawing. The dome thickness varies from 8" at the foundation to 3" (for 50 and 100 PSI) or 4½" (for 200 PSI) at a line located 6'-0" above the footing. The remainder of the dome is of constant thickness.

The foundation and entranceway are designed for plastic deformation. The dome, blast door, and escape hatch door are designed for maximum elastic deformation.

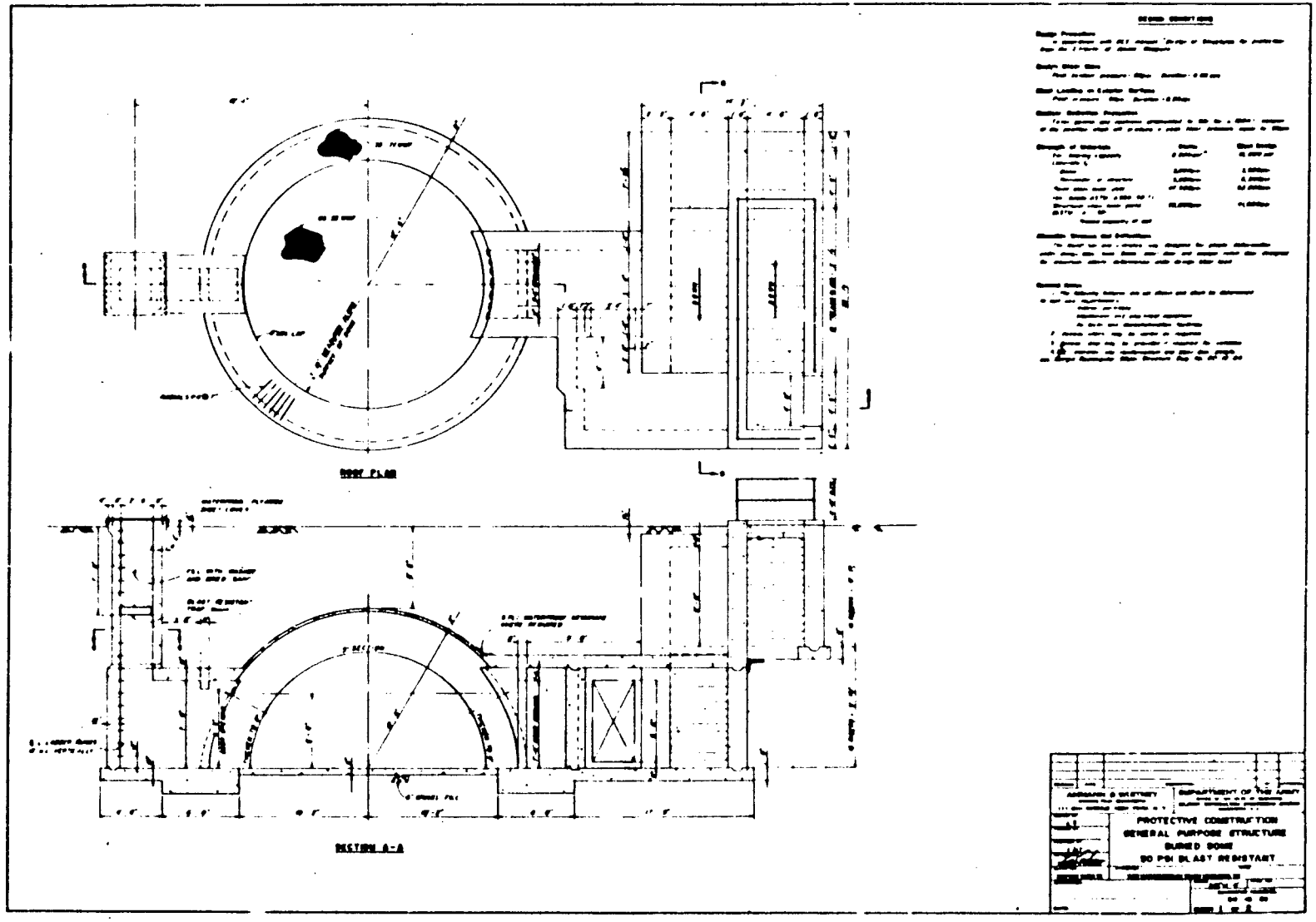

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
BURIED SOME
50 PSI BLAST RESISTANT

Fig. 2.26

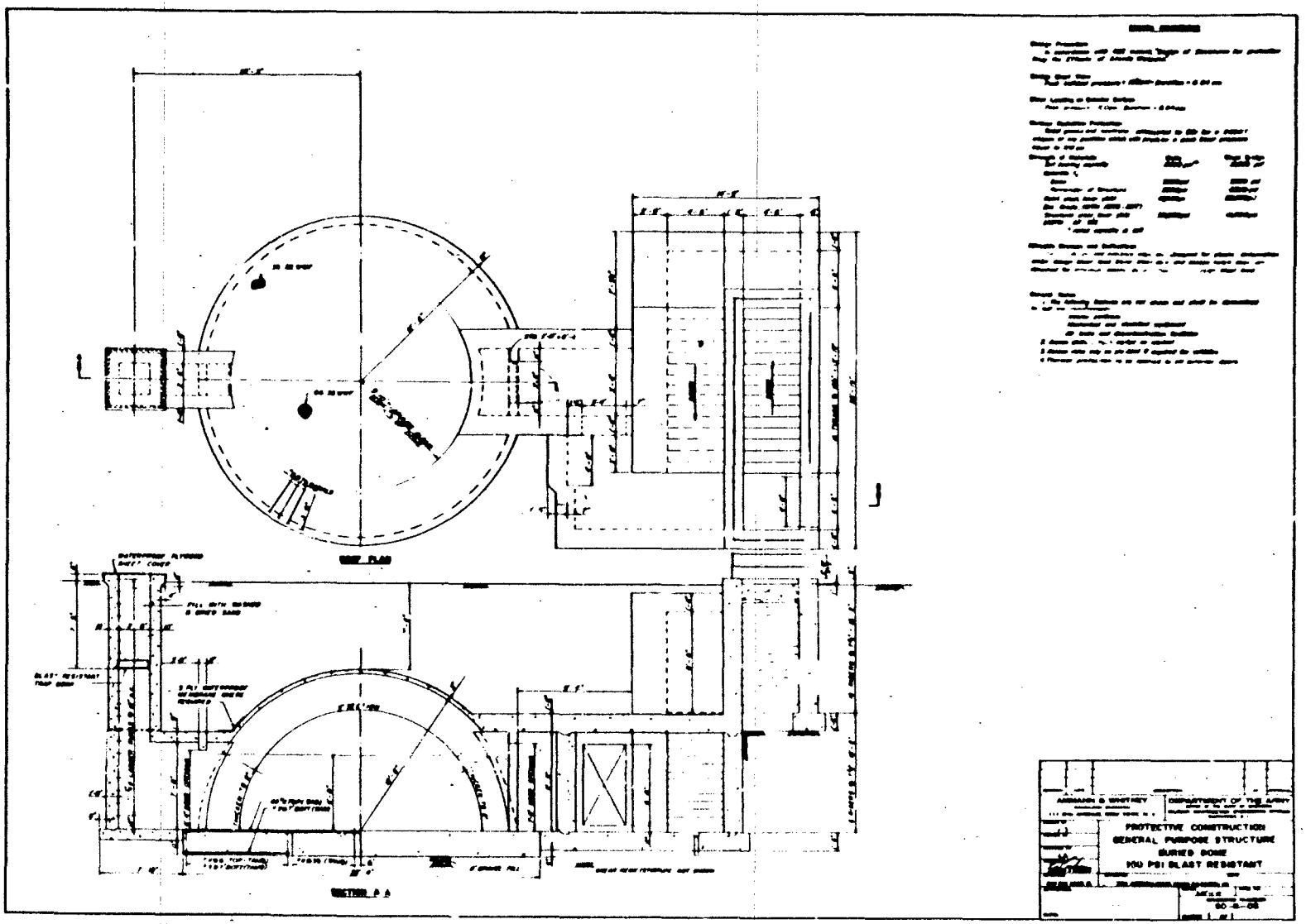

PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
BURIED 600Z
100 PSI BLAST RESISTANT

Fig. 2.27

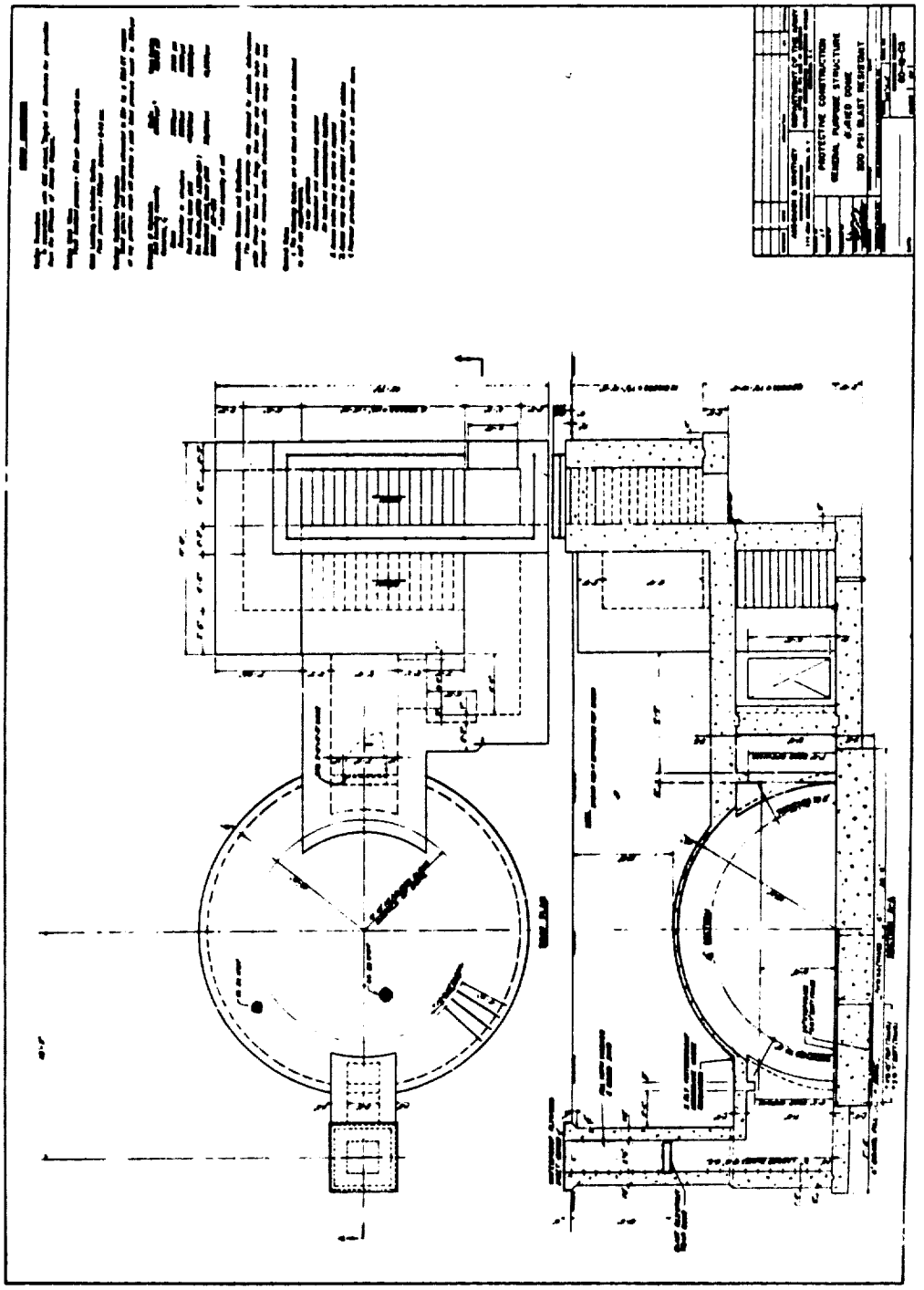


Fig. 2.28

The blast load over the dome surface was assumed as a uniform radial pressure as recommended in the C of E Manual.

2.11 ITEM NO. 11 - BURIED CONCRETE IGLOO (50, 100, 200 PSI)

2.11.1 General

The design of the Buried Concrete Igloo as shown on Ammann & Whitney Drawings No. 60-18-07 conforms to the dimensions stated in the contract and further described in preliminary discussions between representatives of the Contracting Officer and Ammann & Whitney.

2.11.2 Blast Resistant Design (Fig. 1.29 - 1.31)

The proposed structure is a reinforced concrete arch with interior floor dimensions of 60'-8" x 26'-6". The distance between the top of the floor slab and the arch extrados at the crown is 12'-9" (intrados radius = 13'-5"). The arch thickness is 8" for the 50 and 100 PSI levels and 10" for the 200 PSI level. The structure is below grade as required for radiation protection. The entrance consists of a partially covered stairwell which is separated from the main structure by means of a blast resistant steel door. A conventional door for ordinary use and an emergency exit are shown on the drawing.

The foundation, end walls and entranceway are designed for plastic deformation. The arch, blast door and escape hatch door are designed for maximum elastic deformation.

The blast load over the arch surface was assumed as a uniform radial pressure as recommended in the C of E Manual.

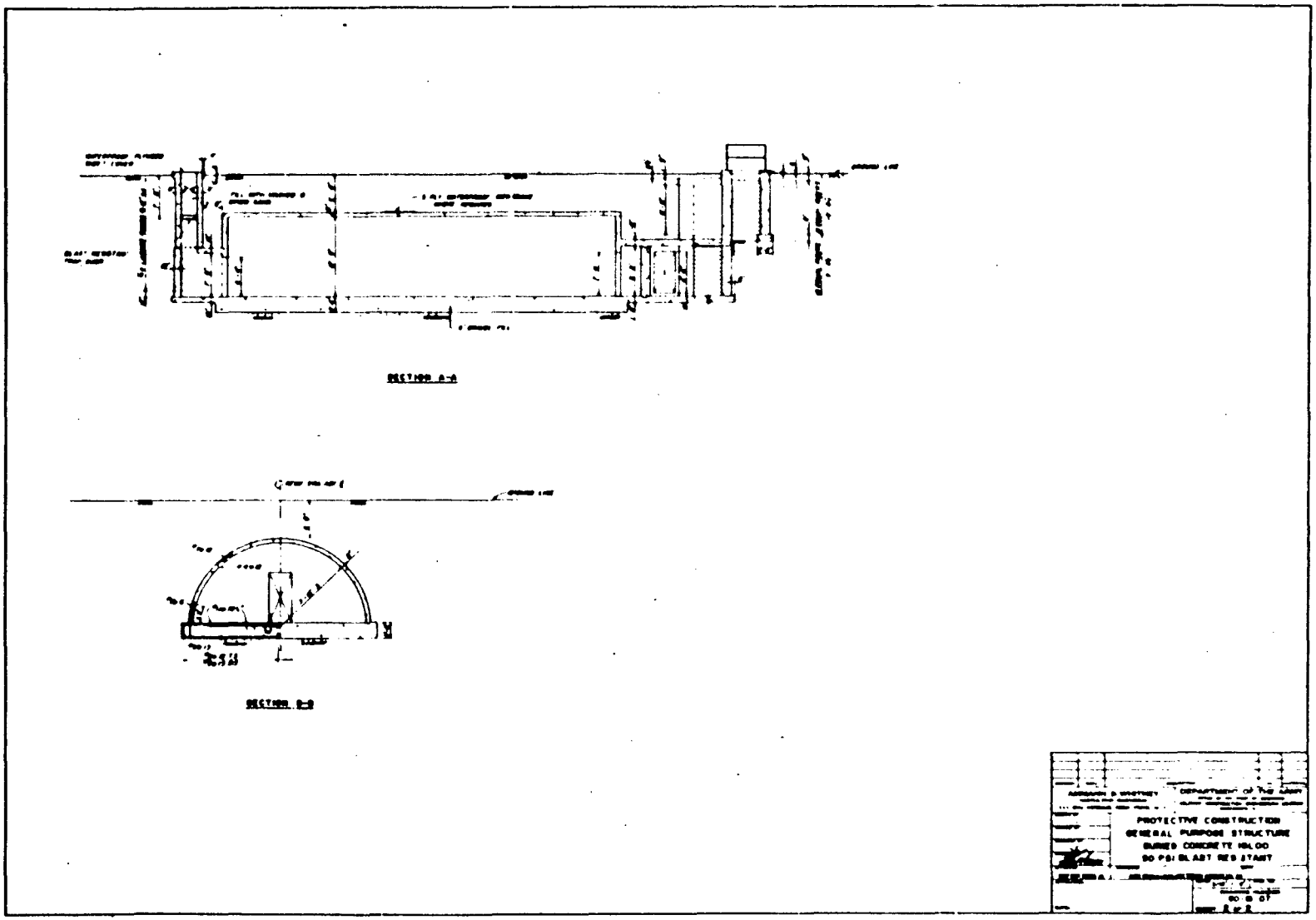


Fig. 2.29

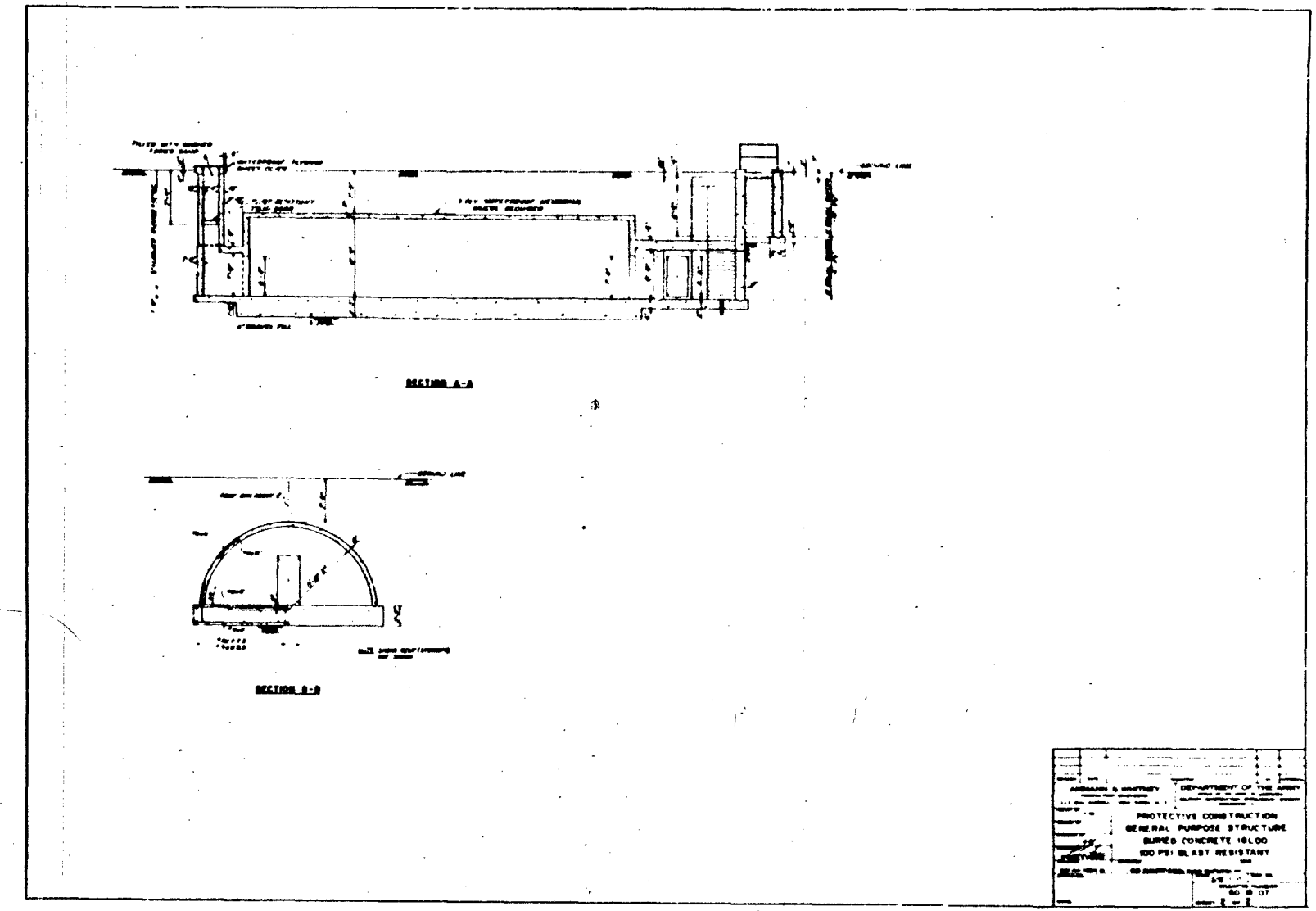

SECTION A-A
SECTION B-B
PROTECTIVE CONSTRUCTION
GENERAL PURPOSE STRUCTURE
BURIED CONCRETE 16L00
100 PSI BLAST RESISTANT

Fig. 2.30

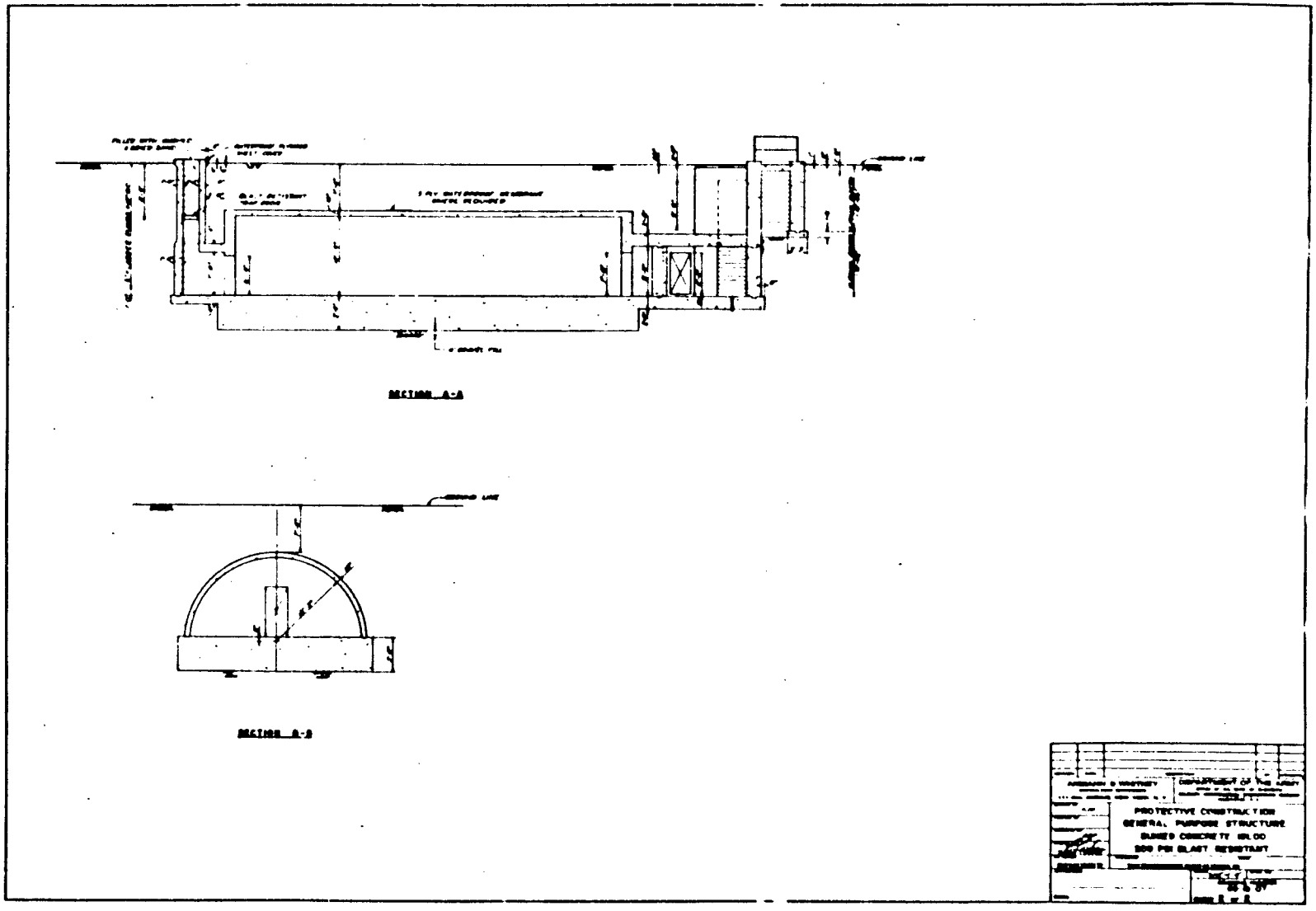


Fig. 2.31

CHAPTER 3 COST OF STRUCTURES

1 GENERAL

Chapter 3 summarizes the estimated quantity of materials and construction costs for the various structures (including entrances, exits and personnel shelters) designed to resist nuclear detonations.

The unit prices used for the structural estimates are based upon national average costs using the National Construction Estimator (1957-1958 Edition) as a guide. The architectural unit prices for items 1, 2 and 3 were taken from the actual costs of the conventional structures used in this study. Unit prices for blast doors and exit hatch doors were obtained from actual costs of similar doors. It was assumed that the structur were above ground water level and that the excavations were free from large amounts of rock.

The total costs for each of the eleven structures studied are shown in Table 3.1. The cost breakdowns for the main structures and shelters of items 1 through 3, and the cost breakdowns for the main structures, entrances and exits for items 4 through 11 are given in Tables 3.2 and 3.3 respectively. The architectural and structural costs and quantity of materials of items 1 through 3, and structural costs and quantity of materials for items 4 through 11 are completely itemized in Appendix A. Additional expenses and increased space allocation

TABLE 3.1-TOTAL COST ESTIMATE SUMMARY-ITEMS 1 THRU 11

ITEM	TITLE	PRESSURE (psi)	COST
(1)	Administration Bldg. - Conventional	—	$ 317,335
	Administration Bldg. - Blast Resistant	10	395,534
	Administration Bldg. - Blast Resistant	20	481,213
	Administration Bldg. - Blast Resistant	30	593,058
(2)	Communication Bldg. - Conventional	—	66,828
	Communication Bldg. - Blast Resistant	10	91,805
	Communication Bldg. - Blast Resistant	20	110,679
	Communication Bldg. - Blast Resistant	30	131,993
(3)	Warehouse - Conventional	—	106,865
	Warehouse - Blast Resistant	10	165,141
	Warehouse - Blast Resistant	20	213,420
	Warehouse - Blast Resistant	30	286,065
(4)	Earth Covered, Concrete Igloo	25	31,788
	Earth Covered, Concrete Igloo	50	52,594
	Earth Covered, Concrete Igloo	100	70,590
	Earth Covered, Concrete Igloo	200	103,775
(5)	Earth Covered, Concrete Rectangular	25	63,566
	Earth Covered, Concrete Rectangular	50	77,086
	Earth Covered, Concrete Rectangular	100	107,561
	Earth Covered, Concrete Rectangular	200	152,128
(6)	Earth Covered, Concrete Double Barrel Arch	50	96,431
(7)	Earth Covered, Concrete Dome	50	23,979
	Earth Covered, Concrete Dome	100	29,428
	Earth Covered, Concrete Dome	200	44,758
(8)	Buried, Concrete Rectangular	50	75,639
	Buried, Concrete Rectangular	100	93,855
	Buried, Concrete Rectangular	200	129,811
(9)	Buried, Concrete Double Barrel Arch	50	79,664
(10)	Buried, Concrete Dome	50	21,913
	Buried, Concrete Dome	100	27,539
	Buried, Concrete Dome	200	34,637
(11)	Buried, Concrete Igloo	50	44,300
	Buried, Concrete Igloo	100	55,393
	Buried, Concrete Igloo	200	70,069

TABLE 3.2 - COST ESTIMATE SUMMARY - ITEMS 1 THRU 3

Item	Title	Pressure (psi)	Main Str. Floor Area (sq. ft.)	Cost		Cost Per Sq. Ft. of Main Str.	
				Main Str.	Shelter	Main Str.	Total
(1)	Administration Bldg. - Conventional	—	34,800	$317,335	$ —	$ 9.12	$ 9.12
	Administration Bldg. - Blast Resistant	10	34,800	372,410	23,124	10.70	11.37
	Administration Bldg. - Blast Resistant	20	34,800	456,983	24,230	13.13	13.83
	Administration Bldg. - Blast Resistant	30	34,800	565,428	27,630	16.25	17.04
(2)	Communications Bldg. - Conventional	—	5,350	66,828	--	12.49	12.49
	Communications Bldg. - Blast Resistant	10	5,350	82,416	9,389	15.40	17.16
	Communications Bldg. - Blast Resistant	20	5,350	100,593	10,086	18.80	20.69
	Communications Bldg. - Blast Resistant	30	5,350	120,155	11,838	22.46	24.67
(3)	Warehouse - Conventional	—	14,790	106,865	—	7.23	7.23
	Warehouse - Blast Resistant	10	14,790	157,507	7,634	10.65	11.17
	Warehouse - Blast Resistant	20	14,790	204,017	9,403	13.79	14.43
	Warehouse - Blast Resistant	30	14,790	272,471	13,594	18.42	19.34

TABLE 3.3 - COST ESTIMATE SUMMARY-ITEMS 4 THRU 11

Item	Title	Pressure (psi)	Main Str. Floor Area (sq. ft.)	Cost		Cost Per Sq. Ft. of Main Str.	
				Entry & Exit	Main Str.	Main Str.	Total
(4)	Earth Covered, Concrete Igloo	25	1,628	$ 10,490	$ 21,298	$ 13.08	$ 19.53
	Earth Covered, Concrete Igloo	50	1,628	16,205	36,389	22.35	32.31
	Earth Covered, Concrete Igloo	100	1,628	20,616	49,974	30.70	43.36
	Earth Covered, Concrete Igloo	200	1,628	32,420	71,355	43.83	63.74
(5)	Earth Covered, Concrete Rectangular	25	3,200	11,964	51,602	16.13	19.86
	Earth Covered, Concrete Rectangular	50	3,200	20,586	56,498	17.66	24.09
	Earth Covered, Concrete Rectangular	100	3,200	24,638	82,923	25.91	33.61
	Earth Covered, Concrete Rectangular	200	3,200	39,083	112,985	35.31	47.54
(6)	Earth Covered, Concrete Double Barrel Arch	50	3,528	19,618	76,813	21.77	27.33
(7)	Earth Covered, Concrete Dome	50	492	16,600	7,379	15.00	48.74
	Earth Covered, Concrete Dome	100	492	20,400	9,028	18.35	59.81
	Earth Covered, Concrete Dome	200	492	32,846	11,912	24.21	90.97
(8)	Buried, Concrete Rectangular	50	3,200	10,597	65,042	20.33	23.64
	Buried, Concrete Rectangular	100	3,200	16,104	77,751	24.30	29.33
	Buried, Concrete Rectangular	200	3,200	23,617	106,194	33.19	40.57
(9)	Buried, Concrete Double Barrel Arch	50	3,528	13,771	65,893	18.68	22.58
(10)	Buried, Concrete Dome	50	492	13,344	8,529	17.34	44.54
	Buried, Concrete Dome	100	492	18,488	9,051	18.40	55.97
	Buried, Concrete Dome	200	492	23,624	11,013	22.38	70.40
(11)	Buried, Concrete Igloo	50	1,628	10,905	33,395	20.51	27.21
	Buried, Concrete Igloo	100	1,628	17,628	37,765	23.20	34.03
	Buried, Concrete Igloo	200	1,628	23,617	46,452	28.53	43.01

will be incurred in the personnel shelter zones of items 1 through 3 for providing such additional equipment and facilities as electronic sensing devices, blast valves, chemical filters, protected cooling water supply (cooling towers, spray ponds or wells) electrical and mechanical standby equipment, lavatory facilities, decontamination facilities and button-up provisions. The cost of such equipment and facilities will depend upon the size of the occupancy and duration of stay. Similar cost increases must be considered for the non-standard type structures, items 4 through 11, if they are to be used for personnel protection.

3.2 STANDARD STRUCTURES

The architectural and structural costs of the standard structures (Items 1, 2 and 3), which are designed to afford blast protection of the entire structures are not increased appreciably by the additional structural cost of personnel shelters. Table 3.4 shows that the percentage cost due to the addition of personnel shelters remains almost constant for the various overpressure levels considered.

TABLE 3.4 PERCENT INCREASE OF THE MAIN STRUCTURE COST BY THE ADDITION OF PERSONNEL SHELTERS

Items	Pressure Level (psi)		
	10	20	30
1	6.2	5.2	4.1
2	11.4	10.0	9.9
3	4.9	4.8	4.7

A plot of the structure cost per sq. foot of floor area versus the overpressure levels for the standard type structures, 1 through 3, is shown in Fig. 3.1. While Fig. 3.2 indicates the unit cost per sq. foot of floor area of the blast variable structural items only. The unit cost of the one story buildings (Items 2 and 3) is shown to be directly proportional to the overpressure level for the range considered. The cost of multi-story structure (Item 1) is directly proportional to the overpressures greater than 10 psi while the overpressure levels less than 10 psi the effects of the architectural cost can be clearly seen. The fact that the multi-story structure cost curve shows a smaller slope than either of the single story structures, up to the overpressure range considered, can be explained in part by the cost saving inherent in the unexposed interior floor slab in the former.

3.3 NON-STANDARD STRUCTURES

The total cost of the non-standard buildings, item 4 through 11, are affected by the type of entrances and exits used. In this cost study, the cost of the entrances and exits varied from 17 to 75 percent of the total cost, depending on the type of structure. In the case of the buried and earth covered dome, the cost of the entrance and exit portion of the structure exceeded the cost of the main chamber by as much as 275 percent. For the majority of the structures studied the entrance and exit portions of structures were approximately

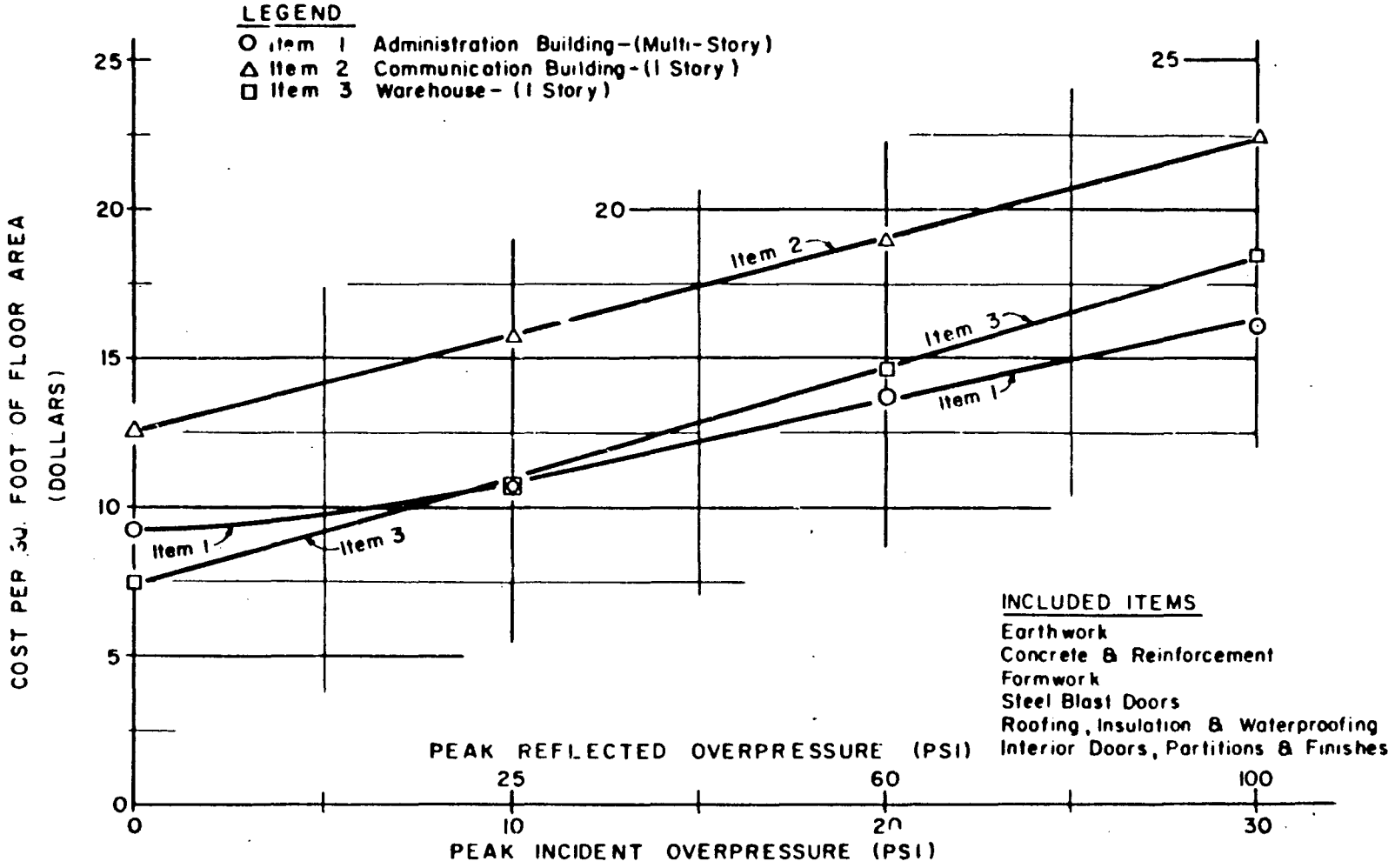


Fig. 3.1 UNIT COSTS OF HARDENING ABOVE GROUND CONVENTIONAL TYPE BUILDINGS (PERSONNEL SHELTER, MECHANICAL & ELECTRICAL COSTS NOT INCLUDED)

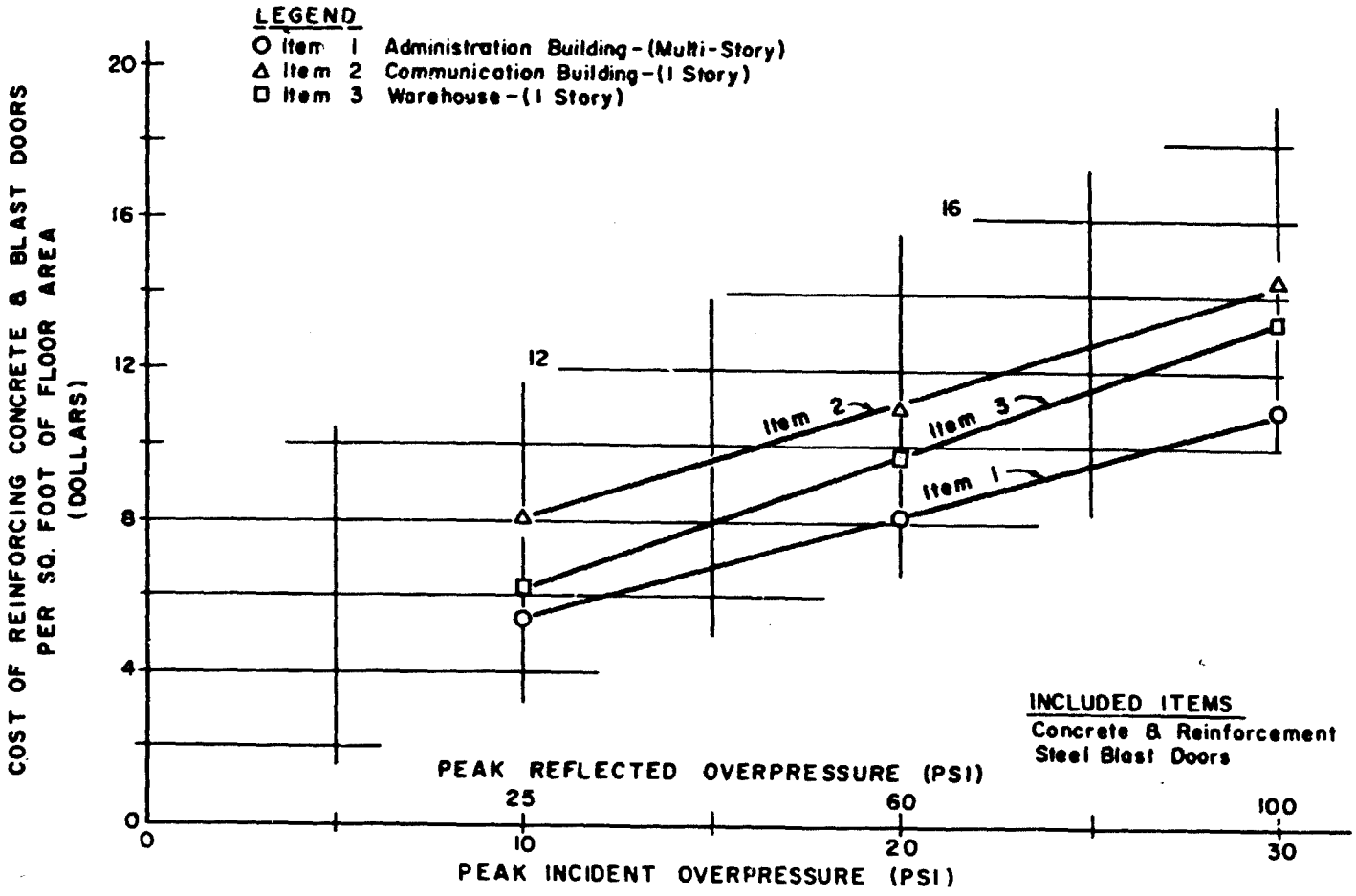


Fig. 3.2 UNIT COSTS OF HARDENING ABOVE GROUND CONVENTIONAL TYPE BUILDINGS (BLAST VARIABLE STRUCTURAL ITEMS ONLY — PERSONNEL SHELTER, MECHANICAL & ELECTRICAL COSTS NOT INCLUDED)

25 percent of the total cost. A substantial cost saving could be achieved for the non-standard structures particularly the dome structure, if the use of the structure would allow the substitution of a vertical shaft type entrance similar to the emergency exit. Further savings may be attained if the structure is not used for radiation protection. A plot of (1) main structure costs, exclusive of entrances and exits, (2) blast variable structural items and (3) total cost versus the overpressure levels are shown in Fig. 3.3, 3.4 and 3.5 respectively.

In the buried arch and dome type structures considered the cost of the shell is only slightly affected by the various design overpressures considered. The shell thicknesses except for the 200 psi level, were determined by minimum requirements for construction. The cost of the earth covered structure, in each case, exceeded that of the buried structure of similar type. In several cases at the lower pressure levels, footings and a "floating" floor slab were used instead of flat plates in the foundation design. This is indicated by the use of dashed lines in Fig. 3.3. 3.4 and 3.5.

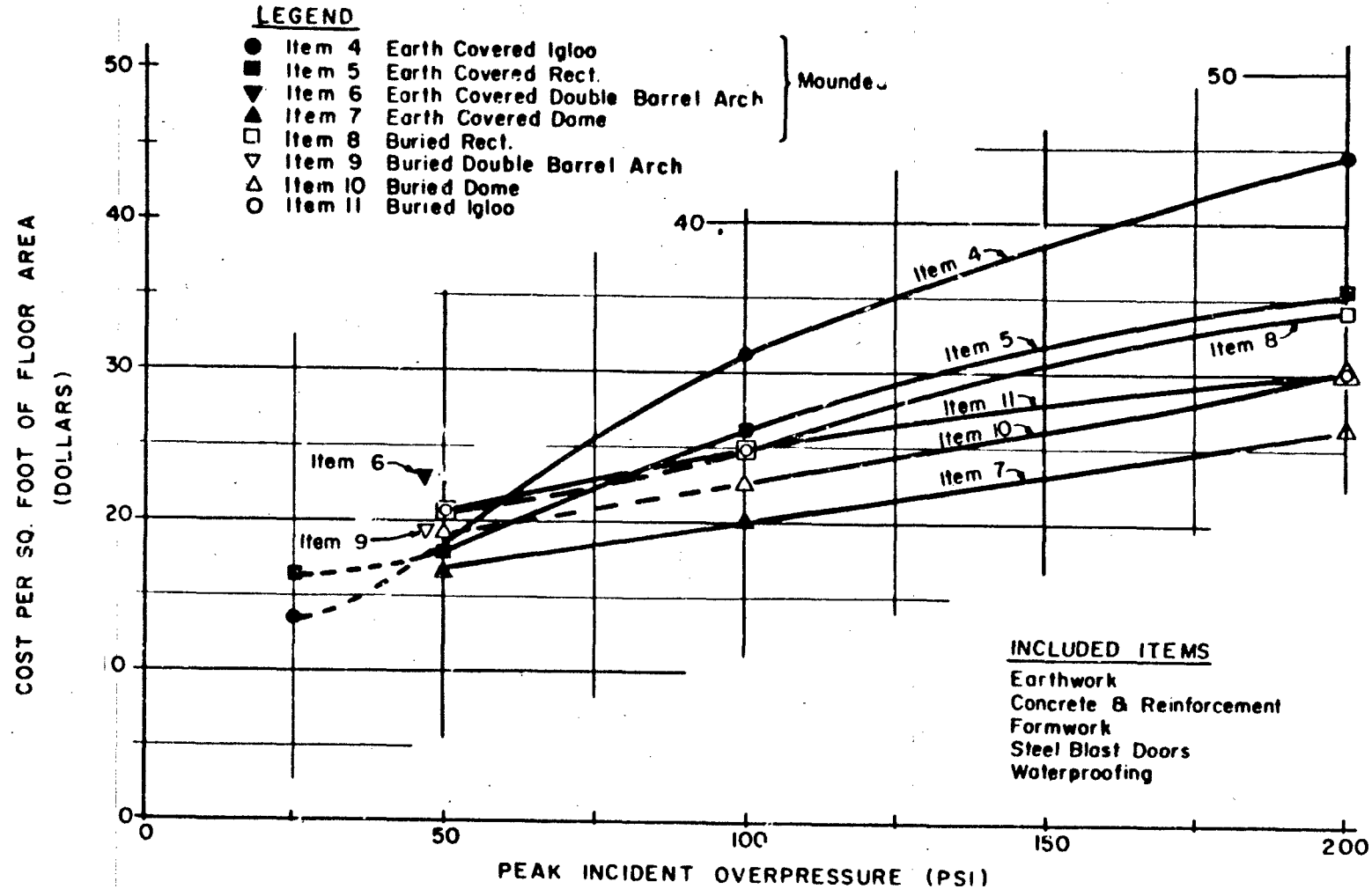


Fig. 3.3 UNIT COSTS FOR HARD MOUNDED AND SHALLOW BURIED STRUCTURES (ENTRANCE WAYS, MECHANICAL AND ELECTRICAL COSTS NOT INCLUDED)

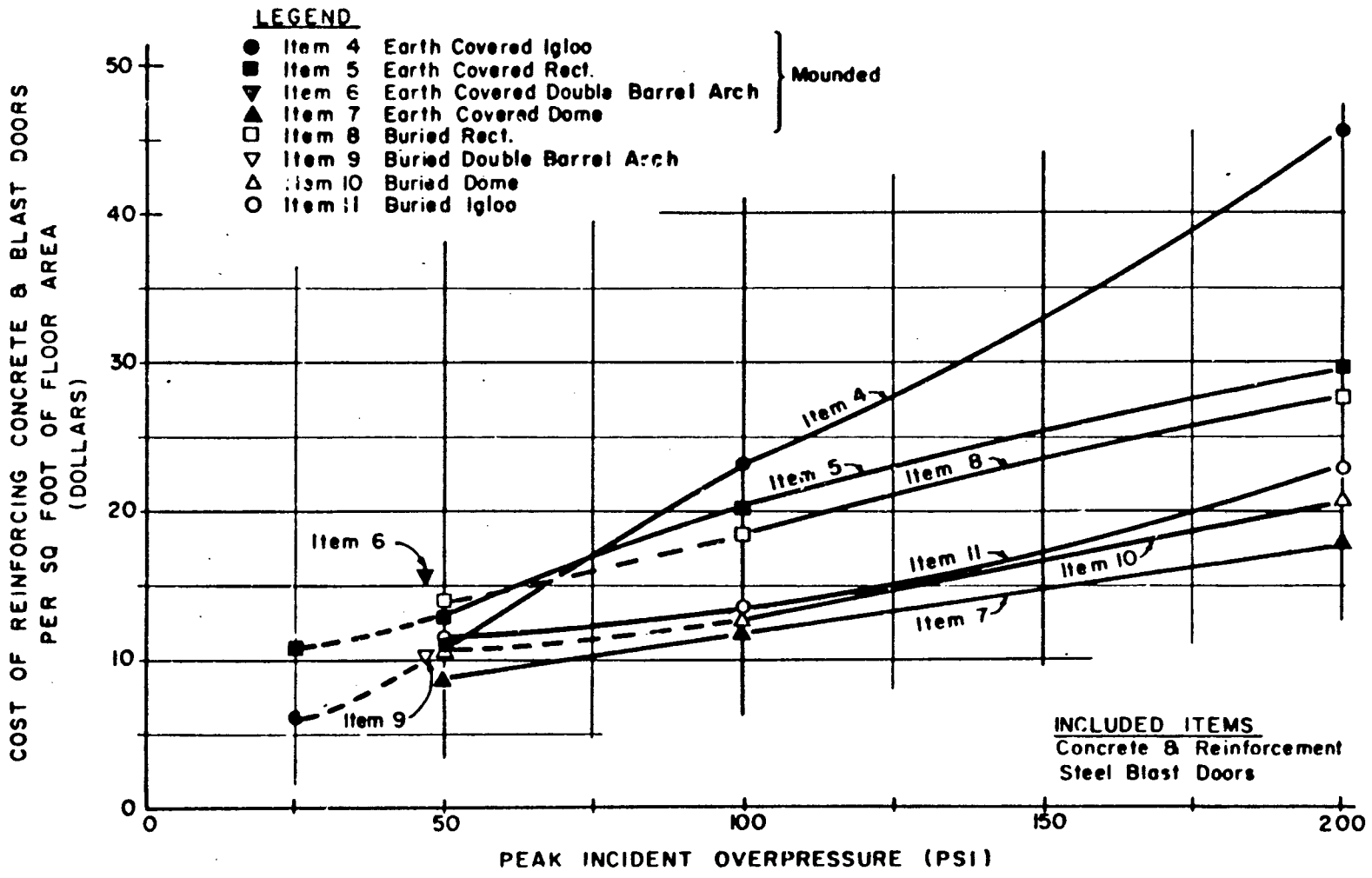


Fig. 3.4 UNIT COSTS FOR HARD MOUNDED AND SHALLOW BURIED STRUCTURES (BLAST VARIABLE STRUCTURAL ITEMS ONLY — ENTRANCE WAYS NOT INCLUDED)

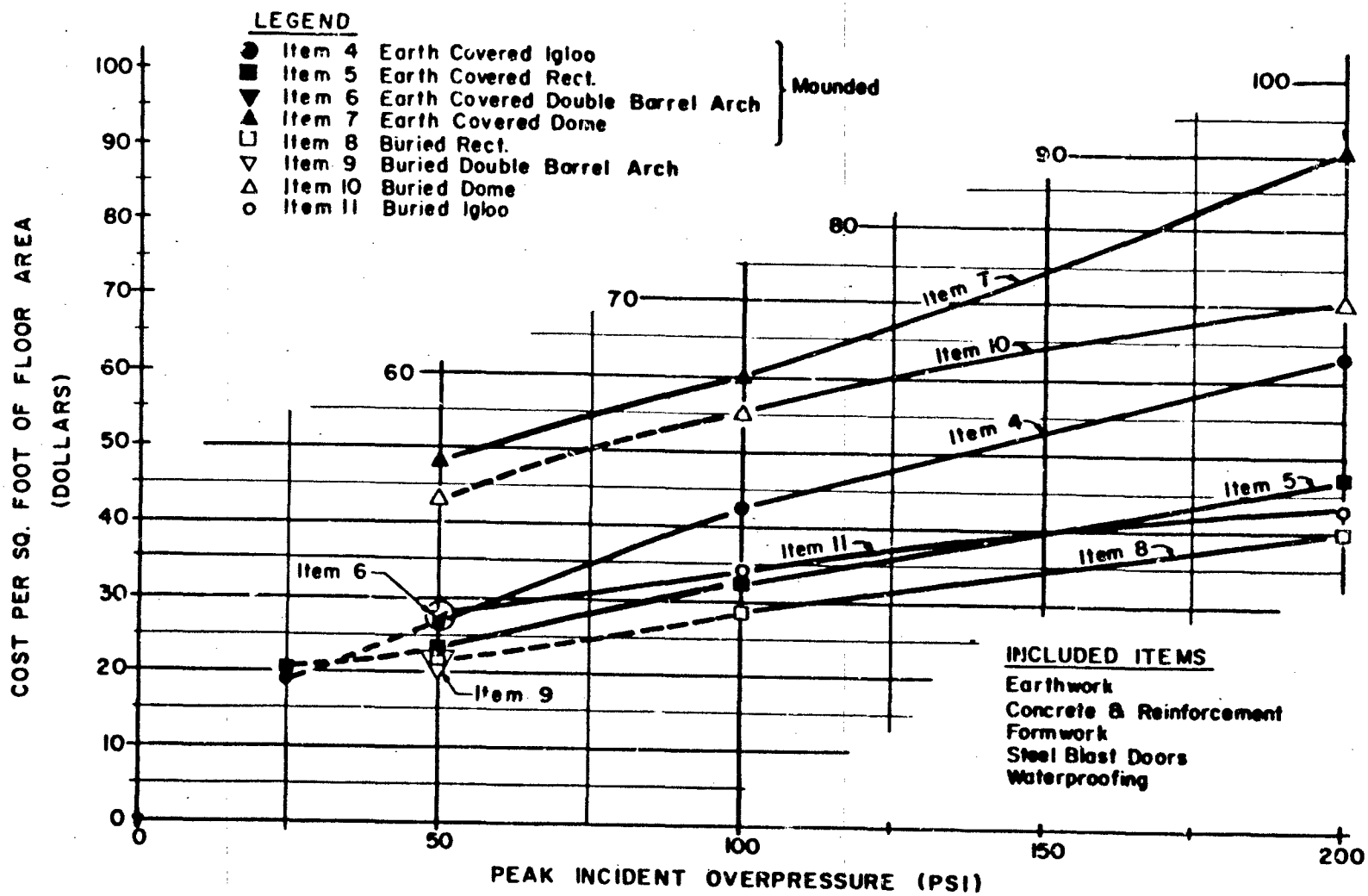


Fig. 3.5 UNIT COSTS FOR HARD MOUNDED AND SHALLOW BURIED STRUCTURES INCLUDING ENTRANCE WAYS AS SHOWN (MECHANICAL AND ELECTRICAL COSTS NOT INCLUDED)

ENGINEERING STUDY OF ATOMIC BLAST RESISTANT DESIGN FOR SEVERAL DIFFERENT BUILDING TYPES

(Contract No. DA 49-129-Eng-317)

APPENDIX A - COST ESTIMATES

COST ESTIMATE - CONVENTIONAL ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Excavation & Fill				
1. machine excavation	C.Y.	3,100	$ 1.35	$ 4,185
2. hand excavation	C.Y.	305	4.00	1,220
3. backfill	C.Y.	960	0.80	768
4. trenching for pipes below floor	L.F.	490	1.50	735
5. select gravel fill	C.Y.	65	3.50	228
6. level & tamp for slab fill	S.F.	15,408	0.03	462
7. random fill under slabs	C.Y.	188	2.00	376
Foundation Concrete				
1. footings	C.Y.	128	30.00	3,840
2. walls	C.Y.	416	30.00	12,480
3. footing forms	S.F.	2,640	0.40	1,056
4. wall forms	S.F.	24,800	0.50	12,400
5. haunch & pier forms	S.F.	1,380	0.80	1,104
6. slabs on ground	C.Y.	216	30.00	6,480
7. 2" precast concrete trench covers	S.F.	2,048	1.65	3,379
8. 3" concrete floor fill	C.Y.	19	30.00	570
9. wood access panels	S.F.	48	1.50	72
10. 3" I trench cover supports	Ton	0.92	380.00	350
11. 1/2" x 5" premoulded exp. joint	L.F.	1,274	0.10	127
12. reinforcing mesh 6x6 - #4x#4	Sq.	162	6.84	1,108
13. reinforcing bars	Ton	7.40	250.00	1,850
14. float finish exterior platforms	S.F.	400	0.15	60
15. paint top of pipe trench wall	S.F.	300	0.08	24
16. platform edge forms	S.F.	70	0.40	28
Concrete Frame				
1. first floor slab & beams	C.Y.	93	30.00	2,790
2. concrete steps, suspended	S.F.	90	7.50	675
3. concrete steps on fill	S.F.	90	4.50	405
4. first floor slab forms	S.F.	4,600	0.75	3,450
5. first floor beam forms	S.F.	680	0.90	612
6. second floor slabs	C.Y.	8	30.00	240
7. second floor slab forms	S.F.	510	0.75	383
8. reinforcing steel	Ton	6.70	250.00	1,675
9. precast concrete plank	S.F.	380	0.90	342

COST ESTIMATE - CONVENTIONAL ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Steel Frame				
1. steel beams & channels	Ton	69.00	380.00	26,220
2. concrete filled pipe columns	Ton	12.60	300.00	3,780
Miscellaneous Iron				
1. Single pipe rail	L.F.	36	2.58	93
2. double pipe rail	L.F.	38	5.90	224
3. steel stairs, pan type safety nosings	R.	36	60.00	2,160
4. gratings & trench covers	S.F.	88	4.80	422
Vault Construction				
1. concrete walls and slabs	C.Y.	62	30.00	1,860
2. wall and slab forms	S.F.	3,425	0.50	1,713
3. reinforcing steel	Ton	2.85	250.00	713
4. trowel slab & apply hardener	S.F.	350	0.15	53
5. vault doors	Ea.	2	360.00	720
Mason Work				
1. 12" concrete block	Bl.	11,900	0.75	8,925
2. 16" concrete U block	Bl.	1,200	1.25	1,500
3. 4" concrete block	Bl.	500	0.40	200
4. concrete fill for block voids	C.Y.	59	30.00	1,770
5. reinforcing bars	Ton	9.30	250.00	2,325
6. masonry wall reinforcing	L.F.	3,500	0.15	525
7. precast concrete sill (5" x 5")	L.F.	771	1.95	1,503
8. firebrick flue lining	Br.	2,900	0.20	580
9. fabric wall flashing	S.F.	2,280	0.60	1,368
10. caulking	S.F.	2,600	0.20	520
11. concrete chimney cap	Ea.	1	55.00	55
12. concrete splash blocks	Ea.	2	20.00	40
Concrete Finishes				
1. trowel for floor covering	S.F.	13,506	0.15	2,026
2. trowel for grano. finish	S.F.	5,230	0.18	941
3. concrete filled stair pans	S.F.	264	0.50	132
4. floor hardener	S.F.	5,230	0.03	157

COST ESTIMATE - CONVENTIONAL ADMINISTRATION BUILDING

	DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Roofing & Metal					
1.	5 ply built up roof and roof insulation U-10 (wd. deck)	S.F.	17,500	0.55	9,625
2.	canopy gravel stop & fascia	L.F.	46	1.30	60
3.	2" pipe conductors	L.F.	24	1.50	36
4.	2" roof drains	Ea.	2	45.00	90
5.	wall flashing	S.F.	156	1.00	156
6.	main roof fascia and gravel stop 20"	L.F.	750	2.20	1,650
7.	wall louvers	Ea.	2	30.00	60
8.	roof drains, main roof	Ea.	7	60.00	420
9.	roof hatch 30" x 36"	Ea.	1	300.00	300
Rough Carpenter Work					
1.	wood spikers	B.F.	3,800	0.28	1,064
2.	fascia & cleat blocking	B.F.	1,286	0.28	360
3.	stud frame	B.F.	14,150	0.22	3,113
4.	floor & roof frame	B.F.	62,300	0.24	14,952
5.	floor & roof boarding	B.F.	37,500	0.20	7,500
6.	gypsum board ceiling	S.F.	26,010	0.12	3,121
7.	1x2 ceiling strapping	S.F.	29,800	0.10	2,980
8.	gypsum wall board	S.F.	36,600	0.12	4,392
9.	1x2 wall furring	S.F.	10,400	0.16	1,064
10.	5/8" plywood sub-floor	S.F.	13,900	0.25	3,475
11.	steel sash	S.F.	4,160	2.60	10,816
12.	glazing	S.F.	4,160	0.35	1,456
13.	asphalt tile 1/8"	S.F.	27,500	0.28	7,700
14.	ceramic tile floor	S.F.	1,200	1.75	2,100
15.	ceramic tile wainscot	S.F.	1,470	1.75	2,573
16.	cement asbestos board dado	S.F.	4,300	0.30	1,290
17.	cement plaster on M.L.	S.Y.	580	3.50	2,030
18.	base screeds	L.F.	486	0.22	107
19.	acoustic tile	S.F.	2,525	0.65	1,641
Exterior Doors & Entrances					
1.	pr. doors, glazed	Ea.	1	315.00	315
2.	pr. doors, glazed with transom	Ea.	5	365.00	1,825
3.	pr. doors, glazed, with removable transom	Ea.	1	390.00	390
4.	single door, glazed with transom	Ea.	1	195.00	195

COST ESTIMATE - CONVENTIONAL ADMINISTRATION BUILDING

	DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
	Interior Doors (Including Frames)				
1.	single, glazed	Ea.	70	70.00	4,900
2.	single, flush	Ea.	16	60.00	960
3.	pair, glazed	Ea.	3	130.00	390
4.	pair, Kalamein	Ea.	3	185.00	555
5.	single, Kalamein	Ea.	5	95.00	475
6.	Dutch doors	Ea.	1	130.00	130
7.	single, tin clad	Ea.	2	85.00	170
8.	channel door frames	Ea.	3	50.00	150
9.	rolling steel door	Ea.	1	—	175
10.	metal toilet compartments	Ea.	12	95.00	1,140
11.	urinal screens	Ea.	5	40.00	200
12.	entrance screens	L.F.	16	15.00	240
13.	mirrors	Ea.	15	25.00	375
14.	toilet room accessories	L.S.	—	—	192
15.	fire extinguishers	Ea.	6	19.00	114
16.	elevator & doors	—	—	—	6,000
17.	painting	—	—	—	11,000
18.	finish hardware	—	—	—	2,000
19.	rough hardware	—	—	—	600
20.	clean up and wash glass	—	—	—	800
	Finish Carpentry				
1.	wood base 6"	L.F.	4,140	0.28	1,159
2.	wood dado cap 3"	L.F.	1,100	0.16	176
3.	movable partitions (without doors)	L.F.	491	13.00	6,383
4.	plastic top shelf (powder room)	L.F.	7	3.00	21
5.	lavatory shelves	Ea.	15	10.00	150
6.	boxing columns	B.F.	1,200	0.60	720
7.	main stairs, wood, 5'-0" wide	R.	18	—	500
8.	wood stairs, 3'-6" wide	R.	18	—	375
9.	closet shelf and pole	L.F.	10	—	15
10.	wood ladder & clg. scuttle	Ea.	1	—	86
11.	wood stool & blocking	L.F.	770	0.80	616
12.	wood sash stops	L.F.	1,900	0.14	266
13.	wood platforms and steps	S.F.	80	2.00	160
14.	court room bench and platform	L.S.	—	—	480
15.	mail room counter	L.F.	23	20.00	460
16.	coffee shop counter	L.F.	43	20.00	860
17.	mop racks	Ea.	2	10.00	20

COST ESTIMATE - CONVENTIONAL ADMINISTRATION BUILDING

	COST
TOTAL SUM	$ 253,868
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	63,467
TOTAL COST	317,335

ITEMS NOT INCLUDED
Costs as taken from original estimate

Plumbing	15,145
Heating	32,258
Electric Work	39,000
	$ 86,403

COST ESTIMATE - 10 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
BUILDING				
Earthwork				
1. machine excavation	C.Y.	2,654	$ 1.35	$ 3,583
2. hand excavation	C.Y.	419	4.00	1,676
3. backfill	C.Y.	669	0.80	535
4. trenching for pipes below floor	L.F.	493	1.50	740
5. level & tamp slab	S.F.	14,025	0.03	421
6. select gravel fill	C.Y.	5	3.50	18
Concrete Work				
1. foundation walls	C.Y.	218	30.00	6,540
2. footings	C.Y.	96	30.00	2,880
3. walls	C.Y.	858	30.00	25,740
4. columns	C.Y.	31	30.00	930
5. floor slabs on grade	C.Y.	270	30.00	8,100
6. floor slabs	C.Y.	943	30.00	28,290
7. beams	C.Y.	216	30.00	6,480
8. stairs	C.Y.	17	30.00	510
9. finishing floor slabs	S.F.	32,146	0.15	4,822
Formwork				
1. footings	S.F.	3,274	0.40	1,310
2. walls	S.F.	60,947	0.60	36,568
3. slabs	S.F.	32,377	0.60	19,426
4. beams	S.F.	8,331	0.90	7,500
5. columns	S.F.	2,147	0.80	1,718
6. stairs	S.F.	960	0.80	768
Reinforcing				
1. rods	Tons	262.00	250.00	65,500
2. wire mesh (66-44)	Sq.	136	6.84	930
Blast Doors				
1. structural steel	Tons	3.70	400.00	1,480
2. Robertson Q deck	Tons	1.00	750.00	750
Roofing				
1. 5 ply built up roof & roof insulation	S.F.	15,145	0.55	8,330

COST ESTIMATE - 10 PSI BLAST RESISTANT ADMINISTRATION BUILDING

	DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
	Mason Work				
1.	4" concrete block	Ea.	1,248	0.40	499
2.	firebrick flue lining	Ea.	2,900	0.20	580
3.	concrete chimney cap	Ea.	1	55.00	55
	Rough Carpenter Work				
1.	stud frame	B.F.	9,437	0.22	2,076
2.	gypsum wall board	S.F.	27,460	0.12	3,295
3.	asphalt tile 1/8"	S.F.	26,877	0.28	7,526
4.	ceramic tile floor	S.F.	1,260	1.75	2,205
5.	ceramic tile wainscot	S.F.	624	1.75	1,092
6.	cement asbestos board dado	S.F.	3,392	0.30	1,018
7.	base screeds	L.F.	156	0.22	34
	Finish Carpentry				
1.	wood base 6"	L.F.	1,937	0.28	542
2.	wood dado cap 3"	L.F.	848	0.16	136
3.	movable partitions (without doors)	L.F.	523	13.00	6,799
4.	plastic top shelf (powder room)	L.F.	7	3.00	21
5.	lavatory shelves	Ea.	15	10.00	150
6.	closet shelf and pole	L.F.	10	1.50	15
7.	wood platforms & steps	S.F.	80	2.00	160
8.	court room bench and platform	L.S.	—	—	480
9.	mail room counter	L.F.	25	20.00	500
10.	coffee shop counter	L.F.	36	20.00	720
11.	mop racks	Ea.	2	10.00	20
	Exterior Doors				
1.	pr. doors, glazed	Ea.	1	315.00	315
2.	pr. doors, glazed with transom	Ea.	5	365.00	1,825
3.	pr. doors, glazed with removable transom	Ea.	1	390.00	390
4.	single door, glazed with transom	Ea.	1	195.00	195

COST ESTIMATE - 10 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Interior Doors (Including Frames) and Interior Details				
1. single, glazed	Ea.	72	70.00	5,040
2. single, flush	Ea.	16	60.00	960
3. pair, glazed	Ea.	3	130.00	390
4. pair, Kalamein	Ea.	4	185.00	740
5. single, Kalamein	Ea.	5	95.00	475
6. Dutch doors	Ea.	1	130.00	130
7. single, tin clad	Ea.	2	85.00	170
8. channel door frames	Ea.	3	50.00	150
9. rolling steel door	Ea.	1	175.00	175
10. metal toilet compartments	Ea.	12	95.00	1,140
11. urinal screens	Ea.	5	40.00	200
12. entrance screens	L.F.	16	15.00	240
13. mirrors	Ea.	15	25.00	375
14. toilets room accessories	L.S.	---	---	192
15. fire extinguishers	Ea.	6	19.00	114
16. vault & shelter doors	Ea.	4	350.00	1,400
17. elevator & doors	---	---	---	6,000
18. painting	---	---	---	11,000
19. finish hardware	---	---	---	2,000
20. rough hardware	---	---	---	600
21. single pipe rail	L.F.	19	2.58	49
22. double pipe rail	L.F.	33	5.90	195
				297,928

Building Sum

SHELTER

Earthwork				
1. machine excavation	C.Y.	1,237	1.35	1,670
2. hand excavation	C.Y.	65	4.00	260
3. backfill	C.Y.	541	0.80	433
4. level and tamp	S.F.	1,721	0.03	52
Concrete Work				
1. footings	C.Y.	15	30.00	450
2. walls	C.Y.	66	30.00	1,980
3. columns	C.Y.	1	30.00	30
4. floor slab on grade	C.Y.	34	30.00	1,020
5. roof slab	C.Y.	62	30.00	1,260
6. beams	C.Y.	5	30.00	150
7. stairs	C.Y.	1	30.00	30
8. finishing floor slab	S.F.	1,822	0.15	273

COST ESTIMATE - 10 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Formwork				
1. footings	S.F.	640	0.40	256
2. walls	S.F.	4,438	0.60	2,663
3. slabs	S.F.	1,580	0.60	948
4. beams	S.F.	368	0.90	332
5. columns	S.F.	120	0.80	96
6. stairs	S.F.	18	0.80	14
Reinforcing				
1. rods	Tons	18.1	250.00	4,528
2. wire mesh (6f-4b)	Sq.	17.8	6.84	122
Waterproofing	S.F.	4,830	0.40	1,932
Shelter Sum				18,499
TOTAL SUM - SHELTER PLUS BUILDING				$ 316,427
PROFIT, OVERHEAD AND CONTINGENCIES (25%)				79,107
TOTAL COST				395,534
COST OF PRIMARY STRUCTURE				372,410
COST OF SHELTER				23,124

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - 20 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
BUILDING				
Earthwork				
1. machine excavation	C.Y.	2,522	$ 1.35	$ 3,405
2. hand excavation	C.Y.	637	4.00	2,548
3. backfill	C.Y.	994	0.80	795
4. trenching for pipes below floor	L.F.	450	1.50	675
5. level & tamp slab	S.F.	15,314	0.03	460
6. select gravel fill	C.Y.	5	3.50	18
Concrete				
1. foundation walls	C.Y.	299	30.00	8,970
2. footings	C.Y.	202	30.00	6,060
3. walls	C.Y.	925	30.00	27,750
4. columns	C.Y.	48	30.00	1,440
5. floor slabs on grade	C.Y.	273	30.00	8,190
6. floor slabs	C.Y.	1,057	30.00	31,710
7. beams	C.Y.	326	30.00	9,780
8. stairs	C.Y.	17	30.00	510
9. finishing floor slabs	S.F.	34,862	0.15	5,229
Formwork				
1. footings	S.F.	4,497	0.40	1,779
2. walls	S.F.	62,253	0.60	37,352
3. slabs	S.F.	30,779	0.60	18,467
4. beams	S.F.	8,742	0.90	7,868
5. columns	S.F.	4,071	0.80	3,257
6. stairs	S.F.	960	0.80	768
Reinforcing				
1. rods	Tons	483	250.00	120,750
2. wire mesh (66-44)	Sq.	136	6.84	930
Blast Doors				
1. structural steel	Tons	7.00	400.00	2,800
2. Robertson Q deck	Tons	1,80	750.00	1,350
Roofing				
1. 5 ply built up roof & roof insulation	S.F.	15,145	0.55	8,330

COST ESTIMATE - 20 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Mason Work				
1. 4" concrete block	Bl.	1,030	0.40	412
2. firebrick flue lining	Br.	2,900	0.20	580
3. concrete chimney cap	Ea.	1	55.00	55
Rough Carpenter Work				
1. stud frame	B.F.	9,437	0.22	2,076
2. gypsum wall board	S.F.	27,460	0.12	3,295
3. asphalt tile 1/8"	S.F.	26,877	0.28	7,526
4. ceramic tile floor	S.F.	1,260	1.75	2,205
5. ceramic tile wainscot	S.F.	624	1.75	1,092
6. cement asbestos board dado	S.F.	3,392	0.30	1,018
7. base screeds	L.F.	156	0.22	34
Finish Carpentry				
1. wood base 6"	L.F.	1,937	0.28	542
2. wood dado cap 3"	L.F.	848	0.16	136
3. movable partitions (without doors)	L.F.	523	13.00	6,799
4. plastic top shelf (powder room)	L.F.	7	3.00	21
5. lavatory shelves	Ea.	15	10.00	150
6. closet shelf and pole	L.F.	10	1.50	15
7. wood platforms & steps	S.F.	80	2.00	160
8. court room bench and platform	L.S.	—	—	480
9. mail room counter	L.F.	25	20.00	500
10. coffee shop counter	L.F.	36	20.00	720
11. mop racks	Ea.	2	10.00	20
Exterior Doors				
1. pr. doors, glased	Ea.	1	315.00	315
2. pr. doors, glased with transom	Ea.	5	365.00	1,825
3. pr. doors, glased with removable transom	Ea.	1	390.00	390
4. single door, glased with transom	Ea.	1	195.00	195

COST ESTIMATE - 20 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Interior Doors (Including Frames) and Interior Details				
1. single, glased	Ea.	72	70.00	5,040
2. single, flush	Ea.	16	60.00	960
3. pair, glased	Ea.	3	130.00	390
4. pair, Kalamein	Ea.	4	185.00	740
5. single, Kalamein	Ea.	5	95.00	475
6. Dutch doors	Ea.	1	130.00	130
7. single, tin clad	Ea.	2	85.00	170
8. channel door frames	Ea.	3	50.00	150
9. rolling steel door	Ea.	1	175.00	175
10. metal toilet compartments	Ea.	12	95.00	1,140
11. urinal screens	Ea.	5	40.00	200
12. entrance screens	L.F.	16	15.00	240
13. mirrors	Ea.	15	25.00	375
14. toilet room accessories	L.S.	—	—	192
15. fire extinguishers	Ea.	6	19.00	114
16. vault & shelter doors	Ea.	1	350.00	1,400
17. elevator & doors	—	—	—	6,000
18. painting	—	—	—	11,000
19. finish hardware	—	—	—	2,000
20. rough hardware	—	—	—	600
21. single pipe rail	L.F.	19	2.58	49
22. double pipe rail	L.F.	33	5.90	195
Building Sum				365,586
SHELTER				
Earthwork				
1. machine excavation	C.Y.	1,302	1.35	1,758
2. hand excavation	C.Y.	68	4.00	272
3. backfill	C.Y.	569	0.80	455
4. level and tamp	S.F.	1,812		55
Concrete				
1. footings	C.Y.	25	30.00	750
2. walls	C.Y.	89	30.00	2,670
3. columns	C.Y.	2	30.00	60
4. floor slab on grade	C.Y.	33	30.00	990
5. roof slab	C.Y.	59	30.00	1,770
6. beams	C.Y.	19	30.00	570
7. stairs	C.Y.	1	30.00	30
8. finishing floor slab	S.F.	1,812	0.15	272

COST ESTIMATE - 20 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Formwork				
1. footings	S.F.	640	0.40	256
2. walls	S.F.	4,438	0.60	2,663
3. slabs	S.F.	1,580	0.60	948
4. beams	S.F.	368	0.90	332
5. columns	S.F.	120	0.80	96
6. stairs	S.F.	18	0.80	14
Reinforcing				
1. rods	Tons	13.5	250.00	3,375
2. wire mesh (66-44)	Sq.	17	6.84	116
Waterproofing	S.F.	4,830	0.40	1,932
Shelter Sum				19,384
TOTAL SUM - SHELTER PLUS BUILDING				384,970
PROFIT, OVERHEAD AND CONTINGENCIES (25%)				96,243
TOTAL COST				481,213
COST OF PRIMARY STRUCTURE				456,983
COST OF SHELTER				24,230

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - 30 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
BUILDING				
Earthwork				
1. machine excavation	C.Y.	2,396	$ 1.35	$ 3,235
2. hand excavation	C.Y.	968	4.00	3,872
3. backfill	C.Y.	1,481	0.80	1,185
4. trenching for pipes below floor	L.F.	411	1.50	617
5. level & tamp slab	S.F.	16,692	0.03	501
6. select gravel fill	C.Y.	5	3.50	18
Concrete				
1. foundation walls	C.Y.	410	30.00	12,300
2. footings	C.Y.	424	30.00	12,720
3. walls	C.Y.	999	30.00	29,970
4. columns	C.Y.	74	30.00	2,220
5. floor slabs on grade	C.Y.	276	30.00	8,280
6. floor and roof slabs	C.Y.	1,184	30.00	35,520
7. beams	C.Y.	450	30.00	13,500
8. stairs	C.Y.	17	30.00	510
9. finishing floor slabs	S.F.	35,559	0.15	5,334
Formwork				
1. footings	S.F.	6,161	0.40	2,464
2. walls	S.F.	63,498	0.60	38,099
3. slabs	S.F.	29,240	0.60	17,544
4. beams	S.F.	9,179	0.90	8,261
5. columns	S.F.	7,735	0.80	6,188
6. stairs	S.F.	960	0.80	768
Reinforcing				
1. rods	Tons	680.00	250.00	170,000
2. wire mesh (66-44)	Sq.	136	6.84	930
Blast Doors				
1. structural steel	Tons	13.20	400.00	5,280
2. Robertson Q deck	Tons	3.20	750.00	2,400
Roofing				
1. 5 ply built up roof & roof insulation	S.F.	15,145	0.55	8,330

COST ESTIMATE - 30 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Mason Work				
1. 4" concrete block	Ea.	1,030	0.40	412
2. firebrick flue lining	Ea.	2,900	0.20	580
3. concrete chimney cap	Ea.	1	55.00	55
Rough Carpenter Work				
1. stud frame	B.F.	9,437	0.22	2,076
2. gypsum wall board	S.F.	27,460	0.12	3,295
3. asphalt tile 1/8"	S.F.	26,877	0.28	7,526
4. ceramic tile floor	S.F.	1,260	1.75	2,205
5. ceramic tile wainscot	S.F.	624	1.75	1,092
6. cement asbestos board dado	S.F.	3,392	0.30	1,018
7. base screeds	L.F.	156	0.22	34
Finish Carpentry				
1. wood base 6"	L.F.	1,937	0.28	542
2. wood dado cap 3"	L.F.	848	0.16	136
3. movable partitions (without doors)	L.F.	523	13.00	6,799
4. plastic top shelf (powder room)	L.F.	7	3.00	21
5. lavatory shelves	Ea.	15	10.00	150
6. closet shelf and pole	L.F.	10	1.50	15
7. wood platforms & steps	S.F.	80	2.00	160
8. court room bench and platform	L.S.	—	—	480
9. mail room counter	L.F.	25	20.00	500
10. coffee shop counter	L.F.	36	20.00	720
11. mop racks	Ea.	2	10.00	20
Exterior Doors				
1. pr. doors, glazed	Ea.	1	315.00	315
2. pr. doors, glazed with transom	Ea.	5	365.00	1,825
3. pr. doors, glazed with removable transom	Ea.	1	390.00	390
4. single door, glazed with transom	Ea.	1	195.00	195

COST ESTIMATE - 30 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Interior Doors (Including Frames) and Interior Details				
1. single, glazed	Ea.	72	70.00	5,040
2. single, flush	Ea.	16	60.00	960
3. pair, glazed	Ea.	3	130.00	390
4. pair, Kalamein	Ea.	4	185.00	740
5. single, Kalamein	Ea.	5	95.00	475
6. Dutch doors	Ea.	1	130.00	130
7. single, tin clad	Ea.	2	85.00	170
8. channel door frames	Ea.	3	50.00	150
9. rolling steel door	Ea.	1	175.00	175
10. metal toilet compartments	Ea.	12	95.00	1,140
11. urinal screens	Ea.	5	40.00	200
12. entrance screens	L.F.	16	15.00	240
13. mirrors	Ea.	15	25.00	375
14. toilet room accessories	L.S.	—	—	192
15. fire extinguishers	Ea.	6	19.00	114
16. vault & shelter doors	Ea.	4	350.00	1,400
17. elevator & doors	—	—	—	6,000
18. painting	—	—	—	11,000
19. finish hardware	—	—	—	2,000
20. rough hardware	—	—	—	600
21. single pipe rail	L.F.	19	2.58	49
22. double pipe rail	L.F.	33	5.90	195
Building Sum				452,342
WORK				
Earthwork				
1. machine excavation	C.Y.	1,367	1.35	1,845
2. hand excavation	C.Y.	71	4.00	284
3. backfill	C.Y.	597	0.80	478
4. level and tamp	S.F.	1,903	0.03	57
Concrete				
1. footings	C.Y.	36	30.00	1,080
2. walls	C.Y.	99	30.00	2,970
3. columns	C.Y.	2	30.00	60
4. floor slab on grade	C.Y.	32	30.00	960
5. roof slab	C.Y.	110	30.00	3,300
6. beams	C.Y.	11	30.00	330
7. stairs	C.Y.	1	30.00	30
8. finishing floor slab	S.F.	1,711	0.15	257

COST ESTIMATE - 30 PSI BLAST RESISTANT ADMINISTRATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Formwork				
1. footings	S.F.	672	0.40	269
2. walls	S.F.	4,660	0.60	2,796
3. slabs	S.F.	1,659	0.60	995
4. beams	S.F.	386	0.90	347
5. columns	S.F.	126	0.80	101
6. stairs	S.F.	19	0.80	15
Reinforcing				
1. rods	Tons	15.5	250.00	3,875
2. wire mesh (66-44)	Sq.	18	6.84	123
Waterproofing	S.F.	4,630	0.40	1,932
Shelter Sum				22,1[illegible]
TOTAL SUM - SHELTER PLUS BUILDING				474,466
PROFIT, OVERHEAD AND CONTINGENCIES (25%)				118,615
TOTAL COST				593,058
COST OF PRIMARY STRUCTURE				565,428
COST OF SHELTER				27,630

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - CONVENTIONAL COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	445	$ 1.35	$ 601
2. hand excavation	C.Y.	15	4.00	60
3. backfill	C.Y.	266	0.80	213
4. gravel fill	C.Y.	98	3.50	343
5. cinder fill	C.Y.	3	1.50	5
Concrete Work				
1. footings	C.Y.	45	30.00	1,350
2. foundation walls	C.Y.	99	30.00	2,970
3. floor slabs	C.Y.	100	30.00	3,000
4. roof slab	C.Y.	57	30.00	1,710
5. roof slab-lightweight fill	C.Y.	42	30.00	1,260
6. concrete fill - block	C.Y.	5	30.00	150
7. finishing slab	S.F.	5,421	0.15	813
8. screed roof fill	S.F.	6,693	0.15	1,004
Formwork				
1. wall footings	S.F.	1,184	0.40	474
2. foundation walls	S.F.	6,024	0.50	3,012
3. soffit	S.F.	1,052	0.50	526
4. edge	S.F.	174	0.50	88
Reinforcing & etc.				
1. rods	Ton	5.90	250.00	1,475
2. paper backed mesh (33-44)	Sq.	74	15.00	1,110
3. wire mesh (66-44)	Sq.	59	6.84	404
4. 1x5 expansion joint	L.F.	706	0.10	71
5. steel joists	Ton	11.40	380.00	4,332
Carpentry				
1. 1x6 wood fascia	L.F.	526	0.55	289
2. 1x4 beveled cant strip	L.F.	556	0.20	111
3. 1x8 fascia	L.F.	30	0.65	20
4. 5/8 marine plywood	S.F.	125	0.45	56
5. 1x6 sheathing	B.F.	130	0.26	34
6. 2x6 rafters	B.F.	183	0.24	44
7. slide windows & counter	Ea.	3	40.00	120
8. messenger shelf	Ea.	1	17.00	17
9. 1x2 furring strip	S.F.	152	0.16	24
10. 1x2 blocking	L.F.	1,200	0.08	96
11. 1x4 trim	L.F.	170	0.18	31
12. 3/16 cem. asbestos	S.F.	232	0.30	70
13. alum. moulding	L.F.	32	0.40	13

COST ESTIMATE - CONVENTIONAL COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Masonry				
1. 8" conc. block (8x8x16)	S.F.	4,168	0.73	3,043
2. 8" conc. lintel block	S.F.	352	1.00	352
3. 4" conc. block	S.F.	2,795	0.45	1,258
4. 5" x 12" conc. sill	L.F.	170	1.50	255
Doors (Frame & Trim)				
1. 2-2'-6"x7'-0"x1-3/4" -x/3-12"x12"	Ea.	1	155.00	155
2. 3'-0"x7'-0"x1-3/4"- w/1-12"x12" lt. sol. core	Ea.	2	85.00	170
3. 2-2'-6"x7'-0"x1-3/4"- w/1-12"x12" lt. sol. core	Ea.	1	145.00	145
4. 3'-0"x7'-0"x1-3/4"-sol core	Ea.	3	80.00	240
5. 3'-0"x6'-8"x1-3/8"-hol. core	Ea.	4	40.00	160
6. 2'-8"x6'-8"x1-3/8"-hol. core	Ea.	2	40.00	80
7. 2'-6"x6'-8"x1-3/8"-hol. core w/louver	Ea.	3	45.00	135
8. 3'-0"x6'-8"x1-3/4" - hol. metal	Ea.	2	65.00	130
9. 8'-0"x7'-0"x1-3/8"- overhead garage dr.	Ea.	2	145.00	290
10. 3'-0"x6'-8"x1-3/4" - hol. metal-w/vis. pan	Ea.	1	80.00	80
11. 2'-8"x6'-8"x1-3/4"- hol. metal	Ea.	1	60.00	60
Hardware				
1. interior doors	Set	13	8.00	110
2. exterior single doors	Set	5	15.00	75
3. exterior double doors	Set	2	30.00	60
4. garage doors	Set	2	20.00	40
Lath & Plaster				
1. metal lath & plaster clg. - S. J.	S.Y.	570	3.50	1,995
2. 3 coat plaster on concrete	S.Y.	275	2.50	688
3. metal lath & plaster on chan.	S.Y.	432	3.50	1,512
4. acoustic plaster on concrete	S.Y.	45	4.20	189
5. acoustic plaster clg. on M.L.	S.Y.	17	5.00	85
6. acoustic plaster on M.L. & chan.	S.Y.	31	6.00	186

COST ESTIMATE - CONVENTIONAL COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Asphalt Tile				
1. 1/8" asphalt tile on concrete	S.Y.	4,175	0.28	1,169
2. 4" rubber base	L.F.	707	0.35	247
Roofing and S. M.				
1. 5 ply B/U roof + 2" rigid insul.	Sq.	68	55.00	3,740
2. 4x6 copper gutter	L.F.	526	2.25	1,183
3. 8" 16 oz. gutter flashing	L.F.	526	0.60	316
4. 16 oz copper gravel stop	L.F.	556	0.70	389
5. Thruwall cap flashing	S.F.	30	1.00	30
6. 2"x4" copper leader	L.F.	91	2.50	228
7. thruwall water block flashing	S.F.	932	1.00	932
8. nervastral sill flashing	S.F.	141	0.20	28
9. alum. wall vents	Ea.	24	7.50	180
10. fan housing flashing	Ea.	2	13.00	26
Water Proofing				
1. 5 ply membrane waterproofing	S.F.	5,284	0.40	2,114
2. foundation waterproofing	S.F.	560	0.15	84
3. interior dampproofing	S.F.	4,498	0.15	675
Glazing				
1. window glass	S.F.	693	0.35	243
2. obscure glass	S.F.	18	0.60	11
3. wire glass	S.F.	33	0.75	28
Miscellaneous Metals				
1. 3" O.D. pipe columns	L.F.	18	2.00	36
2. metal threshold-3"x3'-0"	Ea.	2	15.00	30
3. metal threshold-3"x3'-0"	Ea.	5	15.00	75
4. 6" 8.2# pipe sleeve	Lbs.	66	0.20	13
5. 2'-6"x2'-6"steel trap dr.	Ea.	1	60.00	60
6. 2" pipe sleeve - no caps	Ea.	24	1.00	24
7. 2" pipe sleeve - with caps	Ea.	16	2.50	40
8. 3/4"x12" C.I. ladder rung	Ea.	6	2.10	13
9. misc. bolts and anchors	---	L.S.	100.00	100
Caulking				
1. control joint	L.F.	80	0.20	16
2. windows, doors and grilles	L.F.	950	0.20	190

COST ESTIMATE - CONVENTIONAL COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Metal Windows				
1. 3'-5"x5'-5"-arch proj.	Ea.	13	45.00	585
2. 3'-5"x5'-5"-fixed	Ea.	10	40.00	400
3. 3'-5"x2'-9"-arch proj.	Ea.	4	31.00	124
4. 6'-10"x2'-9"-arch proj.	Ea.	1	55.00	55
5. 6'-10"x2'-9"-fixed	Ea.	8	50.00	400
6. 7'-9"x5'-5"-security	Ea.	1	120.00	120
7. 3'-9"x5'-5"-security	Ea.	2	62.00	124
8. 2'-8-1/2"x1'-10-5/8"-basement	Ea.	1	12.00	12
Ceramic Tile				
1. Wall tile	S.F.	223	1.75	390
2. floor tile	S.F.	95	1.75	166
Painting				
1. doors and windows (3 coats)	S.F.	2,712	0.15	407
2. block (2 coats)	S.F.	6,000	0.10	600
3. plaster (3 coats)	S.F.	11,494	0.12	1,379
4. fascia & trim (3 coats)	S.F.	400	0.12	48
5. steel joists (1 coat)	Ton	11.40	8.00	91
TOTAL SUM				$ 53,462
PROFIT OVERHEAD AND CONTINGENCIES (25%)				13,366
TOTAL COST				66,828

ITEMS NOT INCLUDED
Costs as taken from Original Estimate

Plumbing	1,600
Electrical	7,974
Air Conditioning and Ventilation	13,468
	23,042

COST ESTIMATE - 10 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	660	$1.35	891
2. hand excavation	C.Y.	22	4.00	88
3. backfill	C.Y.	213	0.80	170
4. cinder fill	C.Y.	3	1.50	5
5. gravel fill	C.Y.	99	3.50	347
Concrete Work				
1. roof slab	C.Y.	157	30.00	,710
2. roof beams	C.Y.	21	30.00	630
3. walls	C.Y.	330	30.00	,990
4. floor slab	C.Y.	106	30.00	,180
5. columns	C.Y.	6	30.00	18(
6. footings	C.Y.	60	30.00	,800
7. stairs (on grade)	C.Y.	3	30.00	90
8. finishing slab	S.F.	5,314	0.15	797
Formwork				
1. roof slab	S.F.	4,882	0.60	,929
2. roof beams	S.F.	687	0.90	618
3. walls	S.F.	18,950	0.60	1 370
4. columns	S.F.	586	0.80	469
5. footings	S.F.	1,744	0.40	698
6. stairs (on grade)	S.F.	127	0.80	101
Reinforcing				
1. rods	Tons	59.40	250.00	1 [illegible]50
2. wire mesh (66x44)	Sq.	54	6.84	369
Structural Steel				
1. steel joists	Tons	0.90	380.00	342
Blast Doors				
1. structural steel	Tons	3.70	400.00	[illegible]80
2. Robertson roof deck	Tons	0.50	750.00	375
Masonry				
1. conc. block (8x8x16)	S.F.	470	0.73	343
2. conc. block (4x8x16)	S.F.	1,430	0.45	[illegible]44
3. 5" x 12" conc. sill	L.F.	15	1.50	23

[illegible] - [illegible] BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Carpentry				
1. 1x8 wood fascia	L.F.	70	0.55	39
2. 1x2 beveled cant. strip	L.F.	70	0.20	14
3. slide windows & counter	Ea.	3	40.00	120
4. passenger shelf	Ea.	1	17.00	17
5. 1x2 furring strip	S.F.	152	0.16	24
6. 1x6 blocking	L.F.	1,200	0.08	96
7. 3/16 cem. asbestos	S.F.	232	0.30	70
8. alum. moulding	L.F.	32	0.40	13
Doors (Frame & Trim)				
1. 2-2'-8"x7'-0"x1-3/4"-w/3-12"x12"	Ea.	1	155.00	155
2. 3'-0"x7'-0"x1-3/4"-w/1-12"x12" Lt. Sol. core	Ea.	2	85.00	170
3. 2-2'-6"x7'-0"x1-3/4"-w/1-12"x12" Lt. Sol. core	Ea.	1	145.00	145
4. 3'-0"x7'-0"x1-3/4" - Sol. core	Ea.	3	80.00	240
5. 3'-0"x6'-8"x1-3/8" - Sol. core	Ea.	4	40.00	160
6. 2'-8"x6'-8"x1-3/8" - Hol. core	Ea.	2	40.00	80
7. 2'x6"x6'-8"x1-3/8" - Hol. core w/louvre	Ea.	3	45.00	135
8. 3'-0"x6'-8"x1-3/4" - Hol. metal	Ea.	2	65.00	130
9. 8'-0"x7'-0"x1-3/8" - overhead dr.	Ea.	2	145.00	290
10. 3'-0"x6'-8"x1-3/8" - Hol. metal w/vis. pan	Ea.	1	80.00	80
11. 2'-8"x6'-8"x1-3/4" - Hol. metal	Ea.	1	60.00	60
Hardware				
1. interior doors	Set	13	8.00	104
2. exterior single doors	Set	5	15.00	75
3. exterior double doors	Set	2	30.00	60
4. garage doors	Set	2	20.00	40
Lath & Plaster				
1. metal lath & plaster clg. S.J.	S.Y.	52	3.50	182
2. acoustic plaster on conc.	S.Y.	45	4.20	189
3. acoustic plaster clg. on M.L.	S.Y.	17	5.00	85
4. acoustic plaster on M.L. " chan.	S.Y.	31	6.00	186
Asphalt Tile				
1. 1/8" asphalt tile on conc.	S.F.	4,175	0.28	1,169
2. 4" rubber base	L.F.	707	0.35	247

COST ESTIMATE - 10 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Roofing & Sheet Metal				
1. 5 ply B/U roof + 2" rigid insul.	Sq.	55	55.00	3,025
2. 4x6 copper gutter	L.F.	526	2.25	1,184
3. 8" 16 oz. gutter flashing	L.F.	526	0.60	316
4. 2"x4" copper leader	L.F.	91	2.50	228
5. thruwall cap flashing	S.F.	30	1.00	30
6. thruwall water block flashing	S.F.	932	1.00	932
Waterproofing				
1. 5 ply membrane	S.F.	5,284	0.40	2,114
2. foundation waterproofing	S.F.	560	0.15	84
3. interior dampproofing	S.F.	4,498	0.15	675
Glazing				
1. window glass	S.F.	90	0.35	32
Metal Windows				
1. 3'-5"x5'-5" - arch. proj.	Ea.	3	45.00	135
Miscellaneous Metals				
1. metal threshold - 3"x5'-0"	Ea.	2	15.00	30
2. metal threshold - 3"x3'-0"	Ea.	5	15.00	75
3. 6 8.2# pipe sleeve - 1 unit	Lb.	66	0.20	13
4. 2'-6"x2'-6" steel trap door	Ea.	1	60.00	60
5. 2" pipe sleeves - no caps	Ea.	24	1.00	24
6. 2" pipe sleeves - with caps	Ea.	16	2.50	40
7. 3/4"x12" C.I. ladder rungs	Ea.	6	2.10	13
8. misc. bolts & anchors	L.S.	—	100.00	100
Ceramic Tile				
1. wall tile	S.F.	223	1.75	390
2. floor tile	S.F.	95	1.75	166
Painting				
1. doors & windows (3 coats)	S.F.	1,100	0.15	165
2. concrete & block (2 coats)	S.F.	17,491	0.10	1,749

COST ESTIMATE - 10 PSI BLAST RESISTANT COMMUNICATION BUILDING

	COST
TOTAL SUM	$ 73,444
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	18,361
TOTAL COST	91,805
COST OF PRIMARY STRUCTURE	82,416
COST OF SHELTER	9,389

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - 20 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	841	$ 1.35	$ 1,135
2. hand excavation	C.Y.	45	4.00	180
3. backfill	C.Y.	353	0.80	282
4. cinder fill	C.Y.	3	1.50	5
5. gravel fill	C.Y.	99	3.50	347
Concrete Work				
1. roof slab	C.Y.	211	30.00	6,330
2. roof beams	C.Y.	28	30.00	840
3. walls	C.Y.	371	30.00	11,130
4. floor slab	C.Y.	181	30.00	5,430
5. columns	C.Y.	6	30.00	180
6. footings	C.Y.	73	30.00	2,190
7. stairs (on grade)	C.Y.	3	30.00	90
8. finishing slab	S.F.	5,350	0.15	802
Formwork				
1. roof slab	S.F.	4,705	0.60	2,823
2. roof beams	S.F.	747	0.90	672
3. walls	S.F.	20,644	0.60	12,386
4. columns	S.F.	575	0.80	460
5. footings	S.F.	1,844	0.40	738
6. stairs (on grade)	S.F.	134	0.80	107
Reinforcing				
1. rods	Tons	86.60	250.00	21,650
2. wire mesh (66x44)	Sq.	54	6.84	369
3. paper backed mesh (33x44)	Sq.	5	15.00	75
Structural Steel				
1. steel joists	Tons	0.90	380.00	342
Blast Doors				
1. structural steel	Tons	6.50	400.00	2,600
2. Robertson roof deck	Tons	0.50	750.00	375
Masonry				
1. conc. block (8x8x16)	S.F.	470	0.73	343
2. conc. block (4x8x16)	S.F.	1,430	0.45	644
3. 5"x12" conc. sill	L.F.	15	1.50	23

COST ESTIMATE - 20 PSI BLAST RESISTANT COMMUNICATION BUILDING

	DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
	Carpentry				
1.	1x6 wood fascia	L.F.	70	0.55	39
2.	1x4 beveled cant. strip	L.F.	70	0.20	14
3.	slide windows & counter	Ea.	3	40.00	120
4.	messenger shelf	Ea.	1	17.00	17
5.	1x2 furring strip	S.F.	152	0.16	24
6.	1x2 blocking	L.F.	1,200	0.08	96
7.	3/16 cem. asbestos	S.F.	232	0.30	70
8.	alum. moulding	L.F.	32	0.40	13
	Doors (Frame & Trim)				
1.	2-2'-6"x7'-0"x1-3/4"-w/3-12"x12"	Ea.	1	155.00	155
2.	3'-0"x7'-0"x1-3/4"-w/1-12"x12" Lt. Sol. core	Ea.	2	85.00	170
3.	2-2'-6"x7'-0"x1-3/4"-w/1-12"x12" Lt. Sol. core	Ea.	1	145.00	145
4.	3'-0"x7'-0"x1-3/4" - sol. core	Ea.	3	80.00	240
5.	3'-0"x6'-8"x1-3/8" - Hol. core	Ea.	5	40.00	200
6.	2'-8"x6'-8"x1-3/8" - Hol. core	Ea.	2	40.00	80
7.	2'-6"x6'-8"x1-3/8" - Hol. core w/louvre	Ea.	3	45.00	135
8.	3'-0"x6'-8"x1-3/4" - Hol. metal	Ea.	2	65.00	130
9.	8'-0"x7'-0"x1-3/8" - overhead dr.	Ea.	2	145.00	290
10.	3'-0"x6'-8"x1-3/8" - Hol. metal w/vis. pan.	Ea.	1	80.00	80
11.	2'-8"x6'-8"x1-3/4" - Hol. metal	Ea.	1	60.00	60
	Hardware				
1.	interior doors	Set	13	8.00	104
2.	exterior single doors	Set	5	15.00	75
3.	exterior double doors	Set	2	30.00	60
4.	garage doors	Set	2	20.00	40
	Lath & Plaster				
1.	metal lath & plaster clg. S.J.	S.Y.	52	3.50	182
2.	acoustic plaster on conc.	S.Y.	45	4.20	189
3.	acoustic plaster clg. on M.L.	S.Y.	17	5.00	85
4.	acoustic plaster on M.L. & chan.	S.Y.	31	6.00	186
	Asphalt Tile				
1.	1/8" asphalt tile on conc.	S.F.	4,175	0.28	1,169
2.	4" rubber base	L.F.	707	0.35	247

COST ESTIMATE - 20 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Roofing & Sheet Metal				
1. 5 ply B/U roof + 2" rigid insul.	Sq.	55	55.00	3,025
2. 4x6 copper gutter	L.F.	526	2.25	1,184
3. 8" 16 oz. gutter flashing	L.F.	526	0.60	316
4. 2"x4" copper leader	L.F.	91	2.50	228
5. thruwall cap flashing	S.F.	30	1.00	30
6. thruwall water block flashing	S.F.	932	1.00	932
Waterproofing				
1. 5 ply membrane	S.F.	5,284	0.40	2,114
2. foundation waterproofing	S.F.	560	0.15	84
3. interior dampproofing	S.F.	4,498	0.15	675
Glazing				
1. window glass	S.F.	90	0.35	32
Metal Windows				
1. 3'x5"x5'-5" - arch proj.	Ea.	3	45.00	135
Miscellaneous Metals				
1. metal threshold - 3"x5'-0"	Ea.	2	15.00	30
2. metal threshold - 3"x3'-0"	Ea.	5	15.00	75
3. 6 8.2# pipe sleeve - 1 unit	Lb.	66	0.20	13
4. 2'-6"x2'-6" steel trap door	Ea.	1	60.00	60
5. 2" pipe sleeves - no caps	Ea.	24	1.00	24
6. 2" pipe sleeves - with caps	Ea.	16	2.50	40
7. 3/4x12" C.I. ladder rungs	Ea.	6	2.10	13
8. misc. bolts & anchors	L.S.	—	100.00	100
Ceramic Tile				
1. wall tile	S.F.	223	1.75	390
2. floor tile	S.F.	95	1.75	166
Painting				
1. doors & windows (3 coats)	S.F.	1,100	0.15	165
2. concrete & block (2 coats)	S.F.	17,491	0.10	1,749

COST ESTIMATE - 20 PSI BLAST RESISTANT COMMUNICATION BUILDING

	COST
TOTAL SUM	$ 88,543
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	22,136
TOTAL COST	110,679
COST OF PRIMARY STRUCTURE	100,593
COST OF SHELTER	10,086

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - 30 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	924	$ 1.35	$ 1,247
2. hand excavation	C.Y.	80	4.00	320
3. backfill	C.Y.	408	0.80	326
4. cinder fill	C.Y.	3	1.50	5
5. gravel fill	C.Y.	99	3.50	347
Concrete Work				
1. roof slab	C.Y.	231	30.00	6,930
2. roof beams	C.Y.	40	30.00	1,200
3. walls	C.Y.	547	30.00	16,410
4. floor slab	C.Y.	115	30.00	3,450
5. columns	C.Y.	7	30.00	210
6. footings	C.Y.	110	30.00	3,300
7. stairs (on grade)	C.Y.	3	30.00	90
8. finishing slab	S.F.	5,392	0.15	809
Formwork				
1. roof slab	S.F.	4,660	0.60	2,796
2. roof beams	S.F.	871	0.90	784
3. walls	S.F.	20,958	0.60	12,575
4. columns	S.F.	727	0.80	582
5. footings	S.F.	2,149	0.40	860
6. stairs (on grade)	S.F.	134	0.80	107
Reinforcing				
1. rods	Tons	126.60	250.00	31,650
2. wire mesh (66 x 44)	Sq.	54	6.84	369
3. paper backed mesh (33 x 44)	Sq.	5	15.00	75
Structural Steel				
1. steel joists	Tons	0.90	380.00	342
Blast Doors				
1. structural steel	Tons	8.20	400.00	3,280
2. Robertson roof deck	Tons	0.70	750.00	525
Masonry				
1. conc. block (8x8x16)	S.F.	470	0.73	343
2. conc. block (4x8x16)	S.F.	1,430	0.45	644
3. 5" x 12" conc. sill	L.F.	15	1.50	23

COST ESTIMATE - 30 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Carpentry				
1. 1x6 wood fascia	L.F.	70	0.55	39
2. 1x4 beveled cant. strip	L.F.	70	0.20	14
3. slide windows & counter	Ea.	3	40.00	120
4. messenger shelf	Ea.	1	17.00	17
5. 1x2 furring strip	S.F.	152	0.16	24
6. 1x2 blocking	L.F.	1,200	0.08	96
7. 3/16 cem. asbestos	S.F.	232	0.30	70
8. alum. moulding	L.F.	32	0.40	13
Doors (Frame & Trim)				
1. 2-2'-6"x7'-0"x1-3/4"-w/3-12"x12"	Ea.	1	155.00	155
2. 3'-0"x7'-0"x1-3/4"-w/1-12"x12" Lt. Sol. core	Ea.	2	85.00	170
3. 2-2'-6"x7'-0"x1-3/4"-w/1-12"x12" Lt. Sol. core	Ea.	1	145.00	145
4. 3'-0"x7'-0"x1-3/4" - Sol. core	Ea.	3	80.00	240
5. 3'-0"x6'-8"x1-3/8" - Hol. core	Ea.	5	40.00	200
6. 2'-8"x6'-8"x1-3/8" - Hol. core	Ea.	2	40.00	80
7. 2'-6"x6'-8"x1-3/8" - Hol. core w/louvre	Ea.	3	45.00	135
8. 3'-0"x6'-8"x1-3/4" - Hol. metal	Ea.	2	65.00	130
9. 8'-0"x7'-0"x1-3/8" - overhead dr.	Ea.	2	145.00	290
10. 3'-0"x6'-8"x1-3/8" - Hol. metal w/vis. pan.	Ea.	1	80.00	80
11. 2'-8"x6'-8"x1-3/4" - Hol. metal	Ea.	1	60.00	60
Hardware				
1. interior doors	Set	13	8.00	104
2. exterior single doors	Set	5	15.00	75
3. exterior double doors	Set	2	30.00	60
4. garage doors	Set	2	20.00	40
Lath & Plaster				
1. metal lath & plaster clg. S.J.	S.Y.	52	3.50	182
2. acoustic plaster on conc.	S.Y.	45	4.20	189
3. acoustic plaster clg. on M.L.	S.Y.	17	5.00	85
4. acoustic plaster on M.L. & chan.	S.Y.	31	6.00	186
Asphalt Tile				
1. 1/8" asphalt tile on conc.	S.F.	4,175	0.28	1,169
2. 4" rubber base	L.F.	707	0.35	247

COST ESTIMATE - 30 PSI BLAST RESISTANT COMMUNICATION BUILDING

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Roofing & Sheet Metal				
1. 5 ply B/U roof + 2" rigid insul.	Sq.	55	55.00	3,025
2. 4x6 copper gutter	L.F.	526	2.25	1,184
3. 8" 16 oz. gutter flashing	L.F.	526	0.60	316
4. 2"x4" copper leader	L.F.	91	2.50	228
5. thruwall cap flashing	S.F.	30	1.00	30
6. thruwall water block flashing	S.F.	932	1.00	932
Waterproofing				
1. 5 ply membrane	S.F.	5,284	0.40	2,114
2. foundation waterproofing	S.F.	560	0.15	84
3. interior dampproofing	S.F.	4,498	0.15	675
Glazing				
1. window glass	S.F.	90	0.35	32
Metal Windows				
1. 3'-5"x5'-5" - arch proj.	Ea.	3	45.00	135
Miscellaneous Metals				
1. metal threshold - 3"x5'-0"	Ea.	2	15.00	30
2. metal threshold - 3"x3'-0"	Ea.	5	15.00	75
3. 6 8.2# pipe sleeve - 1 unit	Lb.	66	0.20	13
4. 2'-6"x2'-6" steel trap door	Ea.	1	60.00	60
5. 2" pipe sleeves - no caps	Ea.	24	1.00	24
6. 2" pipe sleeves - with caps	Ea.	16	2.50	40
7. 3/4"x12" C.I. ladder rungs	Ea.	6	2.10	13
8. misc. bolts & anchors	L.S.	---	100.00	100
Ceramic Tile				
1. wall tile	S.F.	223	1.75	390
2. floor tile	S.F.	95	1.75	166
Painting				
1. doors & windows (3 coats)	S.F.	1,100	0.15	165
2. concrete & block (2 coats)	S.F.	17,491	0.10	1,749

COST ESTIMATE - 30 PSI BLAST RESISTANT COMMUNICATION BUILDING

	COST
TOTAL SUM	$ 105,594
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	26,399
TOTAL COST	131,993
COST OF PRIMARY STRUCTURE	120,155
COST OF SHELTER	11,838

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - CONVENTIONAL WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	220	$ 1.35	$ [illegible]
2. hand excavation	C.Y.	20	4.00	[illegible]0
3. backfill	C.Y.	110	0.80	88
4. earthfill	C.Y.	3,016	1.25	3, 770
Concrete Work				
1. roof beams	C.Y.	35	30.00	1, 50
2. columns	C.Y.	49	30.00	1, 470
3. floor slab & platform	C.Y.	350	30.00	10, 500
4. foundation wall	C.Y.	90	30.00	2, 700
5. footings	C.Y.	72	30.00	2, 160
6. window sill	L.F.	104	2.75	286
7. wall coping	C.Y.	1.5	30.00	45
8. stairs (on grade)	C.Y.	6	30.00	180
9. finishing slab	S.F.	18,400	0.15	2, 760
Formwork				
1. roof beams	S.F.	3,000	0.90	2, 700
2. columns	S.F.	6,000	0.80	4, 800
3. platform	S.F.	4,460	0.60	2, 676
4. foundation wall	S.F.	6,850	0.60	4, 110
5. wall coping	S.F.	80	0.60	48
6. stairs (on grade)	S.F.	500	0.60	300
Reinforcing & etc.				
1. rods	Tons	20.10	250.00	5, 025
2. wire mesh (66-44)	Sq.	164	6.84	1, 122
3. 1/2x6 expansion joint	L.F.	926	0.10	93
Masonry				
1. com brick (12" fire wall)	M	21.5	160.00	3, 440
2. conc. block 8x8x16	S.F.	7,500	0.65	4, 875
3. conc. block 4x8x16	S.F.	160	0.40	64
4. conc. block 6x8x16	S.F.	500	0.55	270
Metal Products				
1. pivoted steel sash	S.F.	600	2.00	1, 200
2. thresholds	Ea.	1	15.00	15
3. 1-1/2" pipe rail	Lb.	125	0.40	50
4. 3" pipe rail (door guards)	Lb.	435	0.40	174
5. class "A" fire doors	Ea.	2	200.00	400
6. dove tail anchors	L.F.	1,100	0.35	385
7. glazing	S.F.	416	0.35	146
8. finish hardware	---	L.S.	100.00	100

COST ESTIMATE - CONVENTIONAL WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Millwork				
1. exterior door, frame & trim	Ea.	1	80.00	80
2. interior door, frame & trim	Ea.	4	40.00	160
3. screen doors	Ea.	1	20.00	20
4. overhead doors	Ea.	8	350.00	2,800
5. twin window, frame & trim	Ea.	2	65.00	130
6. single window, frame & trim	Ea.	1	50.00	50
7. 1x4 base	L.F.	100	0.18	18
Carpentry				
1. roof nailer	MFBM	1	150.00	150
2. 1/4" asbestos board	S.F.	2,030	0.25	508
3. 3/4"-1/4 round	L.F.	520	0.15	78
4. door frames (2x8)	MFBM	0.4	300.00	120
5. door frames (1x3)	L.F.	250	0.20	50
6. platform bumper (6x8)	MFBM	2.2	350.00	770
Roof & S.M.				
1. 5 ply built up roof, 1" rigid insulation	S.F.	17,300	0.45	7,785
2. gravel stop	L.F.	480	1.00	480
3. thru wall flashing 36"	L.F.	70	0.60	42
Painting				
1. masonry (2 coats)	S.F.	6,000	0.10	600
2. asbestos board (3 coats)	S.F.	1,500	0.12	180
3. overhead doors (3 coats)	S.F.	1,600	0.20	320
4. wood doors & frames (3 coats)	S.F.	250	0.15	38
5. wood windows & frames (3 coats)	S.F.	90	0.15	14
6. steel windows (3 coats)	S.F.	600	0.20	120
Structural Steel				
1. bar joists	Ton	10.80	350.00	3,780
2. angles & etc.	Ton	3.00	350.00	1,030
Precast channel slab	S.F.	17,300	0.50	8,650
Precast cant strip	L.F.	140	1.00	140

COST ESTIMATE - CONVENTIONAL WAREHOUSE

TOTAL SUM	$ 85,492
PROFIT, OVERHEAD & CONTINGENCIES (25%)	21,373
TOTAL COST	106,865

ITEMS NOT INCLUDED
Cost as taken from Original Estimate

Electrical	3,254
Plumbing	353
Sprinkler System	4,595
Heating & Ventilation	223
	8,425

COST ESTIMATE - 10 PSI BLAST RESISTANT WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	531	$ 1.35	$ 767
2. hand excavation	C.Y.	163	4.00	652
3. backfill	C.Y.	385	0.80	308
4. earthfill	C.Y.	2,190	1.25	2,738
Concrete Work				
1. roof slab	C.Y.	237	30.00	7,110
2. roof beams	C.Y.	205	30.00	6,150
3. columns	C.Y.	20	30.00	600
4. walls & pilasters	C.Y.	598	30.00	17,940
5. floor slab & platform	C.Y.	349	30.00	10,470
6. footings	C.Y.	123	30.00	3,690
7. stairs (on grade)	C.Y.	6	30.00	180
8. finishing slab	S.F.	14,627	0.15	2,194
Formwork				
1. roof slab	S.F.	11,420	0.60	6,852
2. roof beams	S.F.	5,500	0.90	4,950
3. columns	S.F.	1,970	0.80	1,576
4. walls & pilasters	S.F.	32,626	0.60	19,576
5. footings	S.F.	3,171	0.40	1,268
6. stairs (on grade)	S.F.	102	0.80	82
Reinforcing				
1. rods	Ton	99.60	250.00	24,900
2. wire mesh (66-44)	Sq.	150	6.84	1,026
Millwork				
1. exterior door, frame & trim	Ea.	1	80.00	80
2. interior door, frame & trim	Ea.	4	40.00	160
3. screen door	Ea.	1	20.00	20
Blast Doors				
1. structural steel	Ton	7.7	400.00	3,080
2. Robertson Q deck	Ton	2.3	750.00	1,725
Carpentry				
1. platform bumper (6x8)	M.F.B.M.	2.2	350.00	770

COST ESTIMATE - 10 PSI BLAST RESISTANT WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Roofing				
1. 5 ply built up roof 1" rigid insulation	Sq.	173	45.00	7,785
Metal Products				
1. thresholds	Ea.	1	15.00	15
2. 1-1/2" pipe rail	Lb.	218	0.40	87
3. 2" pipe rail (door guards)	Lb.	435	0.40	174
4. class "A" fire doors	Ea.	2	200.00	400
5. steel rool up doors	Ea.	8	500.00	4,000
6. finish hardware	—	L.S.	100.00	100
Painting				
1. concrete (2 coats)	S.F.	6,500	0.10	650
2. wood door & frame (3 coats)	S.F.	250	0.15	38
TOTAL SUM				$ 132,113
PROFIT, OVERHEAD & CONTINGENCIES (25%)				33,028
TOTAL COST				165,141
COST OF PRIMARY STRUCTURE				157,507
COST OF SHELTER				7,634

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - 20 PSI BLAST RESISTANT WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	586	$ 1.35	$ 791
2. hand excavation	C.Y.	200	4.00	800
3. backfill	C.Y.	317	0.80	254
4. earthfill	C.Y.	2,336	1.25	2,920
Concrete Work				
1. roof slab	C.Y.	398	30.00	11,940
2. roof beams	C.Y.	303	30.00	9,090
3. columns	C.Y.	28	30.00	840
4. walls and pilasters	C.Y.	875	30.00	26,250
5. floor slab and platform	C.Y.	351	30.00	10,530
6. footings	C.Y.	255	30.00	7,650
7. stairs (on grade)	C.Y.	6	30.00	180
8. finishing slab	S.F.	14,627	0.15	2,194
Formwork				
1. roof slab	S.F.	11,355	0.60	6,813
2. roof beams	S.F.	6,117	0.90	5,505
3. columns	S.F.	2,423	0.80	1,938
4. walls and pilasters	S.F.	37,136	0.60	22,282
5. footings	S.F.	4,260	0.40	1,704
6. stairs (on grade)	S.F.	105	0.80	84
Reinforcing Steel				
1. rods	Tons	157.00	250.00	39,250
2. wire mesh (66-44)	Sq.	148	6.84	1,012
Blast Doors				
1. structural steel	Tons	8.80	400.00	3,520
2. Robertson roof deck	Tons	2.60	750.00	1,950
Millwork				
1. ext. door, frame and trim	Ea.	1	80.00	80
2. int. door, frame and trim	Ea.	3	40.00	120
3. screen door	Ea.	1	20.00	20
Carpentry				
1. platform bumper (6 x 8)	MFBM	2.2	350.00	770
Roofing				
1. 5 ply built up roof 1" rigid insulation	Sq.	173	45.00	7,785

COST ESTIMATE - 20 PSI BLAST RESISTANT WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Metal Products				
1. threshold	Ea.	1	15.00	15
2. 12" pipe rail	lb.	218	.40	87
3. 2" pipe rail (door guards)	lb.	435	.40	174
4. class A fire door	Ea.	2	200.00	400
5. steel roll up doors	Ea.	6	500.00	3,000
6. finish hardware	L.S.		100.00	100
Painting				
1. concrete (2 coats)		6,500	0.10	650
2. wood, door and frames (2 coats)		250	0.15	38
TOTAL SUM				170,736
PROFIT, OVERHEAD AND CONTINGENCIES (25%)				42,684
TOTAL COST				213,420
COST OF PRIMARY STRUCTURE				204,017
COST OF SHELTER				9,403

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - 30 PSI BLAST RESISTANT WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	780	$ 1.35	$ 1,053
2. hand excavation	C.Y.	446	4.00	1,784
3. backfill	C.Y.	522	0.80	418
4. earthfill	C.Y.	2,345	1.25	2,931
Concrete Work				
1. roof slab	C.Y.	557	30.00	16,710
2. roof beams	C.Y.	453	30.00	13,590
3. columns	C.Y.	42	30.00	1,260
4. walls and pilasters	C.Y.	1,179	30.00	35,370
5. floor slab and platform	C.Y.	353	30.00	10,590
6. footings	C.Y.	494	30.00	14,820
7. stairs (on grade)	C.Y.	6	30.00	180
8. finishing slab	S.F.	14,627	0.15	2,194
Formwork				
1. roof slab	S.F.	11,303	0.60	6,782
2. roof beams	S.F.	7,417	0.90	6,675
3. columns	S.F.	2,994	0.80	2,395
4. walls and pilasters	S.F.	37,813	0.60	22,688
5. footings	S.F.	5,626	0.40	2,250
6. stairs (on grade)	S.F.	107	0.80	86
Reinforcing				
1. rods	Tons	258.00	250.00	64,500
2. welded wire mesh (66-44)	Sqs.	148	6.84	1,012
Blast Doors				
1. structural steel	Tons	13.50	400.00	5,400
2. Robertson roof deck	Tons	3.90	750.00	2,925
Millwork				
1. ext. door, frame and trim	Ea.	1	80.00	80
2. int. door, frame and trim	Ea.	3	40.00	120
3. screen door	Ea.	1	20.00	20
Carpentry				
1. platform bumper (6 x 8)	MFBM	2.2	350.00	770
Roofing				
1. 5 ply built up roof 1" rigid insulation	Sq.	173	45.00	7,785

COST ESTIMATE - 30 PSI BLAST RESISTANT WAREHOUSE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Metal Products				
1. threshold	Ea.	1	15.00	15
2. 1½" pipe rail	lb.	218	.40	87
3. 2" pipe rail (door guards)	lb.	435	.40	174
4. class A fire door	Ea.	2	200.00	400
5. steel roll up doors	Ea.	6	500.00	3,000
6. finish hardware	L.S.		100.00	100
Painting				
1. concrete (2 coats)	S.F.	6,500	0.10	650
2. wood door and frames (3 coats)	S.F.	250	0.15	38
TOTAL SUM				$ 228,852
PROFIT, OVERHEAD AND CONTINGENCIES (25%)				57,213
TOTAL COST				286,065
COST OF PRIMARY STRUCTURE				272,471
COST OF SHELTER				13,594

ITEMS NOT INCLUDED

Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

25 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	75	$ 1.35	$ 101
2. hand excavation	C.Y.	135	4.00	540
3. backfill	C.Y.	156	0.80	45
4. gravel fill	C.Y.	33	3.50	116
5. earth fill	C.Y.	2,707	1.25	3,384
Concrete Work				
1. arch (45° pour)	C.Y.	31	30.00	930
2. arch (45° pour)	C.Y.	31	30.00	930
3. roof slab	C.Y.	13	30.00	390
4. walls	C.Y.	71	30.00	2,130
5. floor slab	C.Y.	61	30.00	1,830
6. footings	C.Y.	61	30.00	1,830
Formwork				
1. arch (45° pour)	S.F.	2,698	1.25	3,373
2. arch (45° pour)	S.F.	1,320	1.25	1,650
3. roof slab	S.F.	353	0.60	212
4. walls	S.F.	4,034	0.60	2,420
5. floor slab	S.F.	235	0.40	94
6. footings	S.F.	552	0.40	221
Reinforcing				
1. rods	Tons	15.30	250.00	3,825
2. wire mesh (66-44)	sq.	16	8.64	138
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.30	1,400.00	140
Carpentry & Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	6,610	0.10	561

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

25 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	$ 25,430
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	6,358
TOTAL COST	31,788
COST OF PRIMARY STRUCTURE	21,298
COST OF ENTRANCE AND EXIT HATCH	10,490

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

50 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	209	$ 1.35	$ 282
2. backfill	C.Y.	23	0.80	18
3. gravel fill	C.Y.	37	3.50	130
4. earthfill	C.Y.	3,146	1.25	,923
Concrete Work				
1. arch (< 45° pour)	C.Y.	33	30.00	990
2. arch (> 45° pour)	C.Y.	33	30.00	990
3. roof slab	C.Y.	18	30.00	540
4. walls	C.Y.	123	30.00	,690
5. floor slab	C.Y.	152	30.00	1,560
Formwork				
1. arch (< 45° pour)	S.F.	2,628	1.25	,285
2. arch (> 45° pour)	S.F.	1,314	1.25	,643
3. roof slab	S.F.	482	0.60	289
4. walls	S.F.	5,489	0.60	,293
5. floor slab	S.F.	639	0.40	256
Reinforcing				
1. rods	Tons	39.00	250.00	,750
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	6,210	0.10	621

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

50 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	$ 35,040
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	8,760
TOTAL COST	43,800
COST OF PRIMARY STRUCTURE	24,354
COST OF ENTRANCE AND EXIT HATCH	15,205

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

100 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	314	1.35	$ 424
2. backfill	C.Y.	36	0.80	29
3. gravel fill	C.Y.	38	3.50	133
4. earth fill	C.Y.	3,522	1.25	4,403
Concrete Work				
1. arch (45° pour)	C.Y.	65	30.00	1,950
2. arch (45° pour)	C.Y.	65	30.00	1,950
3. roof slab	C.Y.	27	30.00	810
4. walls	C.Y.	155	30.00	4,650
5. floor slab	C.Y.	239	30.00	7,170
Formwork				
1. arch (45° pour)	S.F.	2,662	1.25	3,328
2. arch (45° pour)	S.F.	1,331	1.25	1,664
3. roof slab	S.F.	518	0.60	310
4. walls	S.F.	6,028	0.60	3,617
5. floor slab	S.F.	940	0.40	376
Reinforcing				
1. rods	Tons	96.60	250.00	24,150
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.20	1,400.00	280
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	6,580	0.10	658

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

100 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	$ 56,472
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	14,118
TOTAL COST	70,590
COST OF PRIMARY STRUCTURE	49,974
COST OF ENTRANCE AND EXIT HATCH	20,616

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

200 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	505	$ 1.35	$ 682
2. backfill	C.Y.	50	0.80	40
3. gravel fill	C.Y.	39	3.50	137
4. earth fill	C.Y.	3,732	1.25	4,665
Concrete Work				
1. arch (45° pour)	C.Y.	200	30.00	6,000
2. arch (45° pour)	C.Y.	201	30.00	6,030
3. roof slab	C.Y.	36	30.00	1,080
4. walls	C.Y.	269	30.00	8,070
5. floor slab	C.Y.	409	30.00	12,270
Formwork				
1. arch (45° pour)	S.F.	2,704	1.25	3,380
2. arch (45° pour)	S.F.	1,352	1.25	1,690
3. roof slab	S.F.	535	0.60	321
4. walls	S.F.	6,423	0.60	3,854
5. floor slab	S.F.	1,375	0.40	550
Reinforcing				
1. rods	Tons	178.00	250.00	44,500
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch and frame	Tons	0.25	1,400.00	350
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	7,210	0.10	721

COST ESTIMATE - EARTH COVERED CONCRETE IGLOO MAGAZINE

200 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	$ 83,020
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	20,755
TOTAL COST	103,775
COST OF PRIMARY STRUCTURE	71,355
COST OF ENTRANCE AND EXIT HATCH	32,420

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED RECTANGULAR

25 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	140	$ 1.35	$ 189
2. hand excavation	C.Y.	221	4.00	884
3. backfill	C.Y.	75	0.80	60
4. gravel fill	C.Y.	60	3.50	210
5. earth fill	C.Y.	4,054	1.25	5,068
Concrete Work				
1. roof slab	C.Y.	99	30.00	2,970
2. roof beams	C.Y.	70	30.00	2,100
3. columns	C.Y.	4	30.00	120
4. walls & pilasters	C.Y.	217	30.00	6,510
5. floor slab	C.Y.	91	30.00	2,730
6. footings	C.Y.	141	30.00	4,230
Formwork				
1. roof slab	S.F.	2,744	0.60	1,646
2. roof beams	S.F.	1,300	0.90	1,170
3. columns	S.F.	290	0.80	232
4. walls & pilasters	S.F.	10,641	0.60	6,385
5. footings	S.F.	980	0.40	392
Reinforcing				
1. rods	Tons	56.2	250.00	14,050
2. wire mesh (66-44)	Sq.	32	8.64	276
Structural Steel				
1. blast door and frame	Tons	0.3	1,400.00	420
2. exit hatch and frame	Tons	0.10	1,400.00	140
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	9,210	0.10	921

COST ESTIMATE - EARTH COVERED RECTANGULAR

25 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 50,853
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	12,713
TOTAL COST	63,566
COST OF PRIMARY STRUCTURE	51,602
COST OF ENTRANCE AND EXIT HATCH	11,964

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED RECTANGULAR

50 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	268	$ 1.35	$ 362
2. hand excavation	C.Y.	67	4.00	268
3. backfill	C.Y.	41	0.80	33
4. gravel fill	C.Y.	41	3.50	144
5. earth fill	C.Y.	4,931	1.25	6,164
Concrete Work				
1. roof slab	C.Y.	98	30.00	2,940
2. roof beams	C.Y.	121	30.00	3,630
3. columns	C.Y.	5	30.00	150
4. walls and pilasters	C.Y.	264	30.00	7,920
5. floor slab	C.Y.	125	30.00	3,750
6. floor beams	C.Y.	121	30.00	3,630
Formwork				
1. roof slab	S.F.	2,610	0.60	1,566
2. roof beams	S.F.	1,677	0.90	1,509
3. columns	S.F.	234	0.80	187
4. walls and pilasters	S.F.	11,047	0.60	6,628
5. floor slab	S.F.	333	0.40	133
6. floor beams	S.F.	1,532	0.40	213
Reinforcing				
1. rods	Tons	84.5	250.00	21,125
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	10,680	0.10	1,068

COST ESTIMATE - EARTH COVERED RECTANGULAR

50 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 61,669
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	15,417
TOTAL COST	77,086
COST OF PRIMARY STRUCTURE	56,498
COST OF ENTRANCE AND EXIT HATCH	20,586

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED RECTANGULAR

100 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	374	$ 1.35	$ 505
2. hand excavation	C.Y.	143	4.00	572
3. backfill	C.Y.	51	0.80	41
4. gravel fill	C.Y.	36	3.50	126
5. earth fill	C.Y.	5,872	1.25	7,340
Concrete Work				
1. roof slab	C.Y.	149	30.00	4,470
2. roof beams	C.Y.	226	30.00	6,780
3. columns	C.Y.	10	30.00	300
4. walls and pilasters	C.Y.	351	30.00	10,530
5. floor slab	C.Y.	183	30.00	5,490
6. floor beams	C.Y.	196	30.00	5,940
Formwork				
1. roof slab	S.F.	2,480	0.60	1,488
2. roof and floor beams	S.F.	2,075	0.90	1,868
3. columns	S.F.	343	0.80	274
4. walls and pilasters	S.F.	11,763	0.60	7,058
5. floor slab	S.F.	500	.40	200
6. floor beams	S.F.	708	.40	283
Reinforcing				
1. rods	Tons	123.10	250.00	30,775
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.20	1,400.00	280
Carpentry and Millwork				
1. interior door	Ea	1	150.00	150
2.				
Damp Proofing	S.F.	11,590	0.10	1,159

COST ESTIMATE - EARTH COVERED RECTANGULAR

100 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 86,049
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	21,512
TOTAL COST	107,561
COST OF PRIMARY STRUCTURE	82,923
COST OF ENTRANCE AND EXIT HATCH	24,638

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED RECTANGULAR

200 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	529	$ 1.35	$ 714
2. hand excavation	C.Y.	106	4.00	424
3. backfill	C.Y.	55	0.80	44
4. gravel fill	C.Y.	36	3.50	126
5. earth fill	C.Y.	6,094	1.25	7,618
Concrete Work				
1. roof slab	C.Y.	176	30.00	5,280
2. roof beams	C.Y.	330	30.00	9,900
3. columns	C.Y.	20	30.00	600
4. walls and pilasters	C.Y.	592	30.00	17,760
5. floor slab	C.Y.	246	30.00	7,380
6. floor beams	C.Y.	290	30.00	8,700
Formwork				
1. roof slab	S.F.	2,192	0.60	1,315
2. roof beams	S.F.	2,151	0.90	1,936
3. columns	S.F.	486	0.80	389
4. walls and pilasters	S.F.	12,181	0.60	7,309
5. floor slab	S.F.	660	0.40	264
6. floor beams	S.F.	484	0.40	194
Reinforcing				
1. rods	Tons	197.90	250.00	49,475
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch and frame	Tons	0.25	1,400.00	350
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	116.60	0.10	1,166

COST ESTIMATE - EARTH COVERED RECTANGULAR

200 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	121,654
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	30,414
TOTAL COST	152,068
COST OF PRIMARY STRUCTURE	112,985
COST OF ENTRANCE AND EXIT HATCH	39,083

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED DOUBLE BARREL ARCH

50 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	538	$ 1.35	$ 726
2. backfill	C.Y.	42	0.80	34
3. gravel fill	C.Y.	80	3.50	280
4. earth fill	C.Y.	4,836	1.25	6,045
Concrete Work				
1. arch (45° pour)	C.Y.	63	30.00	1,890
2. arch (45° pour)	C.Y.	147	30.00	4,410
3. roof slab	C.Y.	23	30.00	690
4. walls	C.Y.	222	30.00	6,660
5. floor slab	C.Y.	440	30.00	13,200
Formwork				
1. arch (45° pour)	S.F.	3,600	1.25	4,500
2. arch (45° pour)	S.F.	3,600	1.25	4,500
3. roof slab	S.F.	631	0.60	379
4. walls	S.F.	6,775	0.60	4,065
5. floor slab	S.F.	982	0.40	393
Reinforcing				
1. rods	Tons	110.10	250.00	27,525
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Dam; Proofing	S.F.	10,650	0.10	1,065

COST ESTIMATE - EARTH COVERED DOUBLE BARREL ARCH

50 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$77,145
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	19,286
TOTAL COST	96,431
COST OF PRIMARY STRUCTURE	76,813
COST OF ENTRANCE AND EXIT HATCH	19,618

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE DOME

50 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	90	$ 1.35	$ 122
2. backfill	C.Y.	15	0.80	12
3. gravel fill	C.Y.	12	3.50	42
4. earth fill	C.Y.	1,075	1.25	1,344
Concrete Work				
1. dome (45° pour)	C.Y.	12	30.00	360
2. dome (45° pour)	C.Y.	3	30.00	90
3. roof slab	C.Y.	19	30.00	570
4. walls	C.Y.	109	30.00	3,270
5. floor slab	C.Y.	75	30.00	2,250
Formwork				
1. dome (45° pour)	S.F.	1,413	1.25	1,766
2. dome (45° pour)	S.F.	288	1.25	360
3. roof slab	S.F.	488	0.60	293
4. walls	S.F.	4,403	0.60	2,642
5. floor slab	S.F.	402	0.40	161
Reinforcing				
1. rods	Tons	13.80	250.00	4,700
2. wire mesh (66-33)	Sq.	3.0	8.50	26
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	3,950	0.10	395

COST ESTIMATE - EARTH COVERED CONCRETE DOME

50 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 19,183
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	4,796
TOTAL COST	23,979
COST OF PRIMARY STRUCTURE	7,379
COST OF ENTRANCE AND EXIT HATCH	16,600

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE DOME

100 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	128	$ 1.35	$ 173
2. backfill	C.Y.	21	0.80	17
3. gravel fill	C.Y.	12	3.50	42
4. earth fill	C.Y.	1,170	1.25	1,463
Concrete Work				
1. dome (45°pour)	C.Y.	12	30.00	360
2. dome (45°pour)	C.Y.	3	30.00	90
3. roof slab	C.Y.	28	30.00	840
4. walls	C.Y.	133	30.00	3,990
5. floor slab	C.Y.	107	30.00	3,210
Formwork				
1. dome (45°pour)	S.F.	1,413	1.25	1,766
2. dome (45°pour)	S.F.	288	1.25	360
3. roof slab	S.F.	489	0.60	293
4. walls	S.F.	4,610	0.60	2,766
5. floor slab	S.F.	579	0.40	232
Reinforcing				
1. rods	Tons	26.60	250.00	6,650
2. wire mesh (66-33)	Sq.	3.0	8.50	26
Structural Steel				
1. blast door and frame	Tons	0.30	1,400.00	420
2. exit hatch and fra.	Tons	0.20	1,400.00	280
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	4,140	0.10	414

COST ESTIMATE - EARTH COVERED CONCRETE DOME

100 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL	23,542
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	5,886
TOTAL COST	29,428
COST OF PRIMARY STRUCTURE	9,028
COST OF ENTRANCE AND EXIT HATCH	20,400

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - EARTH COVERED CONCRETE DOME

200 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	208	$ 1.35	$ 281
2. backfill	C.Y.	31	0.80	25
3. gravel fill	C.Y.	12	3.50	42
4. earth fill	C.Y.	1,383	1.25	1,729
Concrete Work				
1. dome ($\leq 45°$ pour)	C.Y.	12	30.00	360
2. dome ($> 45°$ pour)	C.Y.	4	30.00	120
3. roof slab	C.Y.	40	30.00	1,200
4. walls	C.Y.	219	30.00	6,570
5. floor slab	C.Y.	176	30.00	5,280
Formwork				
1. dome ($\leq 45°$ pour)	S.F.	1,413	1.25	1,766
2. dome ($> 45°$ pour)	S.F.	288	1.25	360
3. roof slab	S.F.	567	0.60	340
4. walls	S.F.	5,015	0.60	3,009
5. floor slab	S.F.	854	0.40	342
Reinforcing				
1. rods	Tons	51.30	250.00	12,825
2. wire mesh (4x4-4/4)	Sq.	3.0	10.63	32
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch and frame	Tons	0.25	1,400.00	350
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Damp Proofing	S.F.	4,660	0.10	466

COST ESTIMATE - EARTH COVERED CONCRETE DOME

200 PSI BLAST RESISTANT STRUCTURES

	COST
TOTAL SUM	$ 35,807
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	8,952
TOTAL COST	44,759
COST OF PRIMARY STRUCTURE	11,912
COST OF ENTRANCE AND EXIT HATCH	32,846

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED RECTANGULAR

50 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	3,283	$ 1.35	$ 4,432
2. hand excavation	C.Y.	337	4.00	1,348
3. backfill	C.Y.	1,820	0.80	1,456
4. gravel fill	C.Y.	60	3.50	210
Concrete Work				
1. roof slab	C.Y.	88	30.00	2,640
2. roof beams	C.Y.	110	30.00	3,300
3. columns	C.Y.	8	30.00	240
4. walls & pilasters	C.Y.	191	30.00	5,730
5. floor slab	C.Y.	66	30.00	1,980
6. footings	C.Y.	225	30.00	6,750
7. stairs (on grade)	C.Y.	7	30.00	210
Formwork				
1. roof slab	S. F.	2,232	0.60	1,339
2. roof beams	S. F.	1,680	0.90	1,512
3. columns	S. F.	305	0.80	244
4. walls & pilasters	S. F.	7,634	0.60	4,580
5. footings	S. F.	1,410	0.40	564
6. stairs (on grade)	S. F.	80	0.80	64
Reinforcing				
1. rods	Tons	78.00	250.00	19,500
2. wire mesh (66-44)	Sq.	32	8.64	276
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	8,500	0.40	3,400

COST ESTIMATE - BURIED RECTANGULAR

50 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 60,515
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	15,124
TOTAL COST	75,639
COST OF PRIMARY STRUCTURE	65,042
COST OF ENTRANCE AND EXIT HATCH	10,597

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED RECTANGULAR

100 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	3,522	$ 1.35	$ 4,755
2. hand excavation	C.Y.	71	4.00	284
3. backfill	C.Y.	1,432	0.80	1,146
4. gravel fill	C.Y.	39	3.50	137
Concrete Work				
1. roof slab	C.Y.	127	30.00	3,810
2. roof beams	C.Y.	197	30.00	5,910
3. columns	C.Y.	9	30.00	270
4. walls & pilasters	C.Y.	346	30.00	10,380
5. floor slab	C.Y.	138	30.00	4,140
6. floor beams	C.Y.	170	30.00	5,100
7. stairs (on grade)	C.Y.	9	30.00	270
Formwork				
1. roof slab	S.F.	2,086	0.60	1,252
2. roof beams	S.F.	2,009	0.90	1,808
3. columns	S.F.	324	0.80	259
4. walls & pilasters	S.F.	9,647	0.60	5,788
5. floor beams	S.F.	839	0.40	336
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	94.70	250.00	23,675
Structural Steel				
1. blast door and frame	Tons	0.95	1,400.00	1,330
2. exit hatch and frame	Tons	0.20	1,400.00	280
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	9,849	0.40	3,940

COST ESTIMATE - BURIED RECTANGULAR

100 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 75,004
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	18,771
TOTAL COST	93,855
COST OF PRIMARY STRUCTURE	77,751
COST OF ENTRANCE AND EXIT HATCH	16,104

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED RECTANGULAR

200 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	3,660	$ 1.35	$ 4,941
2. hand excavation	C.Y.	100	4.00	400
3. backfill	C.Y.	1,229	0.80	983
4. gravel fill	C.Y.	35	3.50	123
Concrete Work				
1. roof slab	C.Y.	150	30.00	4,500
2. roof beams	C.Y.	244	30.00	7,320
3. columns	C.Y.	20	30.00	600
4. walls & pilasters	C.Y.	450	30.00	13,500
5. floor slab	C.Y.	147	30.00	4,410
6. floor beams	C.Y.	214	30.00	6,420
7. stairs (on grade)	C.Y.	10	30.00	300
Formwork				
1. roof slab	S.F.	1,769	0.60	1,061
2. roof beams	S.F.	2,151	0.90	1,936
3. columns	S.F.	547	0.80	438
4. walls & pilasters	S.F.	10,366	0.60	6,220
5. floor beams	S.F.	1,042	0.40	417
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	172.20	250.00	43,050
Structural Steel				
1. blast door and frame	Tons	2.00	1,400.00	2,800
2. exit hatch and frame	Tons	0.25	1,400.00	350
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	9,915	0.40	3,966

COST ESTIMATE - BURIED RECTANGULAR

200 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 103,849
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	25,962
TOTAL COST	129,811
COST OF PRIMARY STRUCTURE	106,194
COST OF ENTRANCE AND EXIT HATCH	23,617

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED DOUBLE BARREL ARCH

50 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	4,484	$ 1.35	$ 6,053
2. hand excavation	C.Y.	436	4.00	1,744
3. backfill	C.Y.	3,065	0.80	2,452
4. gravel fill	C.Y.	62	3.50	217
Concrete Work				
1. arch (45° pour)	C.Y.	44	30.00	1,320
2. arch (45° pour)	C.Y.	85	30.00	2,550
3. roof slab	C.Y.	10	30.00	300
4. walls	C.Y.	174	30.00	5,220
5. floor slab	C.Y.	75	30.00	2,250
6. footings	C.Y.	294	30.00	8,820
7. stairs (on grade)	C.Y.	8	30.00	240
Formwork				
1. arch (45° pour)	S.F.	3,576	1.25	4,470
2. arch (45° pour)	S.F.	3,325	1.25	4,156
3. roof slab	S.F.	280	0.60	168
4. walls	S.F.	6,256	0.60	3,754
5. footings	S.F.	154	0.40	62
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	62.30	250.00	15,575
2. wire mesh (66-44)	Sq.	35.2	8.64	304
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	7,730	0.40	3,092

COST ESTIMATE - BURIED DOUBLE BARREL ARCH

50 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 63,731
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	15,933
TOTAL COST	79,664
COST OF PRIMARY STRUCTURE	65,893
COST OF ENTRANCE AND EXIT HATCH	13,771

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED CONCRETE DOME

50 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	1,082	$ 1.35	$ 1,461
2. hand excavation	C.Y.	33	4.00	132
3. backfill	C.Y.	751	0.80	601
4. gravel fill	C.Y.	9	3.50	32
Concrete Work				
1. dome (45° pour)	C.Y.	12	30.00	360
2. dome (45° pour)	C.Y.	3	30.00	90
3. roof slab	C.Y.	10	30.00	300
4. walls	C.Y.	88	30.00	2,640
5. floor slab	C.Y.	21	30.00	630
6. footings	C.Y.	46	30.00	1,380
7. stairs (on grade)	C.Y.	8	30.00	240
Formwork				
1. dome (45° pour)	S.F.	1,413	1.25	1,766
2. dome (45° pour)	S.F.	288	1.25	360
3. roof slab	S.F.	283	0.60	170
4. walls	S.F.	2,872	0.60	1,723
5. footings	S.F.	485	0.40	194
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	12.10	250.00	3,025
2. wire mesh (66-44)	Sq.	4.9	8.64	42
(66-33)	Sq.	3.0	8.50	26
(33-22)	Sq.	7.5	19.85	149
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch and frame	Tons	0.15	1,400.00	210
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	3,065	0.40	1,226

COST ESTIMATE - BURIED CONCRETE DOME

50 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 17,530
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	4,383
TOTAL COST	21,913
COST OF PRIMARY STRUCTURE	8,569
COST OF ENTRANCE AND EXIT HATCH	13,344

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED CONCRETE DOME

100 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	965	$ 1.35	$ 1,303
2. backfill	C.Y.	574	0.80	459
3. gravel fill	C.Y.	12	3.50	42
Concrete Work				
1. dome (45° pour)	C.Y.	12	30.00	360
2. dome (45° pour)	C.Y.	3	30.00	90
3. roof slab	C.Y.	14	30.00	420
4. walls	C.Y.	127	30.00	3,810
5. floor slab	C.Y.	75	30.00	2,250
6. stairs (on grade)	C.Y.	10	30.00	300
Formwork				
1. dome (45° pour)	S.F.	1,413	1.25	1,766
2. dome (45° pour)	S.F.	288	1.25	360
3. roof slab	S.F.	257	0.60	154
4. walls	S.F.	4,020	0.60	2,412
5. floor slab	S.F.	178	0.40	71
6. stairs (on grade)	S.F.	86	0.80	69
Reinforcing				
1. rods	Tons	19.55	250.00	4,888
2. wire mesh (66-33)	Sq.	3.0	8.50	26
(33-22)	Sq.	7.5	19.85	149
Structural Steel				
1. blast door and frame	Tons	0.95	1,400.00	1,330
2. exit hatch and frame	Tons	0.20	1,400.00	280
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	2,937	0.40	1,[illegible]

COST ESTIMATE - BURIED CONCRETE DOME

100 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 22,031
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	5,508
TOTAL COST	27,539
COST OF PRIMARY STRUCTURE	9,051
COST OF ENTRANCE AND EXIT HATCH	18,488

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED CONCRETE DOME

200 PSI BLAST RESISTANT STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	1,015	$ 1.35	$ 1,370
2. backfill	C.Y.	475	0.80	380
3. gravel fill	C.Y.	12	3.50	42
Concrete Work				
1. dome (45° pour)	C.Y.	12	30.00	360
2. dome (45° pour)	C.Y.	4	30.00	120
3. roof slab	C.Y.	19	30.00	570
4. walls	C.Y.	165	30.00	4,950
5. floor slab	C.Y.	103	30.00	3,090
6. stairs (grade)	C.Y.	10	30.00	300
Formwork				
1. dome (45° pour)	S.F.	1,413	1.25	1,766
2. dome (45° pour)	S.F.	288	1.25	360
3. roof slab	S.F.	219	0.60	131
4. walls	S.F.	3,525	0.60	2,115
5. floor slab	S.F.	267	0.40	107
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	29.00	250.00	7,250
2. wire mesh (66-22)	Sq.	3.0	9.80	29
(33-00)	Sq.	7.5	27.06	203
Structural Steel				
1. blast door and frame	Tons	2.00	1,400.00	2,800
2. exit hatch and frame	Tons	0.25	1,400.00	350
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	3,005	0.40	1,202

COST ESTIMATE - BURIED CONCRETE DOME

200 PSI BLAST RESISTANT STRUCTURE

	COST
TOTAL SUM	$ 27,709
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	6,927
TOTAL COST	34,637
COST OF PRIMARY STRUCTURE	11,013
COST OF ENTRANCE AND EXIT HATCH	23,624

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED CONCRETE IGLOO

50 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	2,104	$ 1.35	$2,840
2. backfill	C.Y.	1,066	0.80	852
3. gravel fill	C.Y.	36	3.50	126
Concrete Work				
1. arch (45° pour)	C.Y.	31	30.00	930
2. arch (45° pour)	C.Y.	31	30.00	930
3. roof slab	C.Y.	10	30.00	300
4. walls	C.Y.	113	30.00	3,390
5. floor slab	C.Y.	202	30.00	6,060
6. stairs (on grade)	C.Y.	8	30.00	240
Formwork				
1. arch (45° pour)	S.F.	2,480	1.25	3,100
2. arch (45° pour)	S.F.	1,240	1.25	1,550
3. roof slab	S.F.	272	0.60	163
4. walls	S.F.	3,815	0.60	2,289
5. floor slab	S.F.	622	0.40	249
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	37.70	250.00	9,425
Structural Steel				
1. blast door and frame	Tons	0.40	1,400.00	560
2. exit hatch door and frame	Tons	0.15	1,400.00	210
Carpentry & Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	5,050	0.40	2,020

COST ESTIMATE - BURIED CONCRETE IGLOO

50 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	35,448
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	8,862
TOTAL COST	44,300
COST OF PRIMARY STRUCTURE	33,300
COST OF ENTRANCE AND EXIT HATCH	10,905

ITEMS NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED CONCRETE ICLOO

100 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	2,330	$ 1.35	$ 3,146
2. backfill	C.Y.	1,198	0.80	952
3. gravel fill	C.Y.	36	3.50	126
Concrete Work				
1. arch (45° pour)	C.Y.	31	30.00	930
2. arch (45° pour)	C.Y.	31	30.00	930
3. roof slab	C.Y.	14	30.00	420
4. walls	C.Y.	137	30.00	4,110
5. floor slab	C.Y.	261	30.00	7,830
6. stairs (on grade)	C.Y.	10	30.00	300
Formwork				
1. arch (45° pour)	S.F.	2,560	1.25	3,200
2. arch (45° pour)	S.F.	1,280	1.25	1,600
3. roof slab	S.F.	249	0.60	149
4. walls	S.F.	4,710	0.60	2,826
5. floor slab	S.F.	616	0.40	246
6. stairs (on grade)	S.F.	83	0.80	66
Reinforcing				
1. rods	Tons	54.90	250.00	13,725
Structural Steel				
1. blast door and frame	Tons	0.95	1,400.00	1,330
2. exit hatch and frame	Tons	0.20	1,400.00	280
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	4,995	0.40	1,998

COST ESTIMATE - BURIED CONCRETE IGLOO

100 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	44,314
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	11,079
TOTAL COST	55,393
COST OF PRIMARY STRUCTURE	37,765
COST OF ENTRANCE AND EXIT HATCH	17,628

ITEM NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

COST ESTIMATE - BURIED CONCRETE BLOCK

200 PSI BLAST RESISTANCE STRUCTURE

DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	COST
Earthwork				
1. machine excavation	C.Y.	2,671	$ 1.35	$ 3,606
2. backfill	C.Y.	909	0.80	727
3. gravel fill	C.Y.	37	3.50	130
Concrete Work				
1. arch (45° pour)	C.Y.	42	30.00	1,260
2. arch (45° pour)	C.Y.	42	30.00	1,260
3. roof slab	C.Y.	19	30.00	570
4. walls	C.Y.	193	30.00	5,790
5. floor slab	C.Y.	441	30.00	13,230
6. stairs (on grade)	C.Y.	10	30.00	300
Formwork				
1. arch (45° pour)	S.F.	2,480	1.25	3,100
2. arch (45° pour)	S.F.	1,240	1.25	1,550
3. roof slab	S.F.	219	0.60	131
4. walls	S.F.	4,435	0.60	2,661
5. floor slab	S.F.	1,060	0.40	424
6. stairs (on grade)	S.F.	80	0.80	64
Reinforcing				
1. rods	Tons	64.00	250.00	16,000
Structural Steel				
1. blast door and frame	Tons	2.00	1,400.00	2,800
2. exit hatch and frame	Tons	0.25	1,400.00	350
Carpentry and Millwork				
1. interior door	Ea.	1	150.00	150
Water Proofing				
1. 5 ply membrane	S.F.	4,880	0.40	1,952

COST ESTIMATE - BURIED CONCRETE IGLOO

200 PSI BLAST RESISTANCE STRUCTURE

	COST
TOTAL SUM	56,055
PROFIT, OVERHEAD AND CONTINGENCIES (25%)	14,014
TOTAL COST	70,069
COST OF PRIMARY STRUCTURE	46,452
COST OF ENTRANCE AND EXIT HATCH	23,617

ITEM NOT INCLUDED

Interior partitions
Mechanical and electrical equipment
Air locks and decontamination facilities

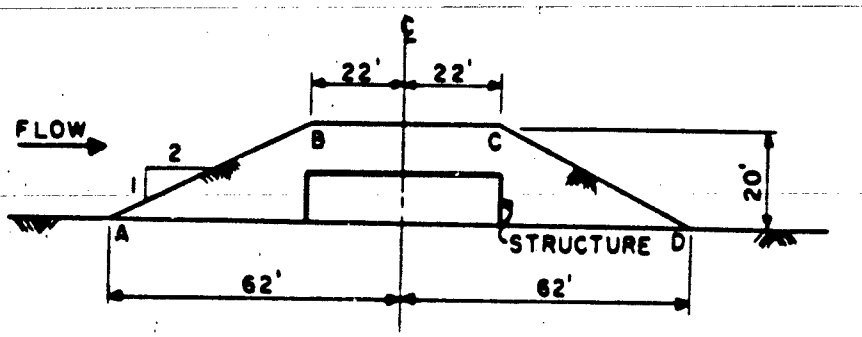
APPENDIX B - TRANSONIC PRESSURES ON ABOVE GROUND EARTH COVERED STRUCTURES

B.1 INTRODUCTION

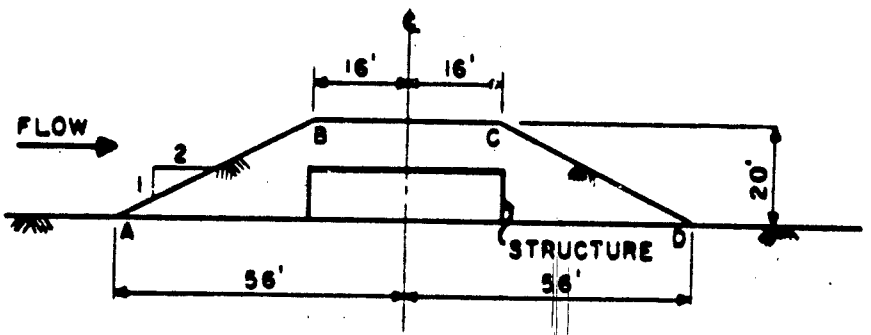
This appendix is concerned with the calculation of nuclear blast pressures on above-ground earth covered structures, such as shown in Fig. B.1 which will be applicable to pressure levels above 25 psig.

Blast loading on structures may be divided into two stages, i.e., the diffraction phase and the enveloped phase. When the pressure at the rear of the surface attains the value of the pressure in the blast wave, the diffraction process may be considered to have terminated, and subsequently, steady state conditions may be assumed to exist until the pressures have returned to the ambient value prevailing prior to the arrival of the blast wave. The diffraction phase pressures on the surface of the earth cover may be computed by conventional methods (Ref. 1), however little information is available concerning the enveloped phase pressures. The enveloped phase pressures consist of the incident pressures plus the dynamic pressures. This appendix presents a solution for obtaining the enveloped phase pressures on wedge shaped earth covers similar to those shown in Fig. B.1. The pressures transmitted through the earth to the structure may be computed by methods described in Reference 1 or by use of a Mohr's Circle Solution. The results are compared with the equivalent circle solution given in Reference 1.

The flows considered are those behind the shock waves whose characteristics are given in Table B.1



(a) Case 1



(b) Case 2

FIG. B.1 ABOVE-GROUND EARTH COVERED STRUCTURES

TABLE B.1 SHOCK WAVE CHARACTERISTICS, 25 PSIG TO 200 PSIG

shock pressures, psig	25	50	100	200
Dynamic pressure, psig	12.2	41	123	330
Shock velocity, ft/sec	1756	2216	2927	3985
Sound velocity behind shock, ft/sec	1309	1447	1681	2064
Particle velocity behind shock, ft/sec	868	1375	2082	3059
Temperature at shock, Deg. Kelvin	379	467	636	968
Density at shock, $\rho \times 10^{7}$ lbs/in^3	871	1161	1526	1895
Mach number behind shock	0.664	0.951	1.239	1.481
Stagnation pressure behind shock psia	53.5	116	294	766

The flow and the structures are considered two dimensional. This is conservative with respect to the pressures on the structure. The effect of the structures being finite in the direction perpendicular to the plane of Fig. B.1 is to reduce somewhat the pressures near the ends of the structure as compared to the pressures computed in the following paragraphs.

B.2 GENERAL FEATURES OF THE FLOW

The general features of the flow depend on the Mach number of the given conditions behind the original shock wave. The Mach number is the ratio of the particle velocity to the velocity of sound. When all parts of a flow have a Mach number less than one the flow is called subsonic. If the Mach number is everywhere greater than one, the flow is called supersonic. If the Mach

number is less than one in some places and greater than one in other parts of the same flow, it is called transonic. All of the combinat ons of initial flows and the geometries given, fall in the transonic range for which both experiments and theory are, unfortunately, relatively scarce and complex.

In the subsonic case the usual concept of pressure coefficients, Cp, to be multiplied by the dynamic pressure, $1/2\rho V^2$, are applicable. Coefficients given for incompressible flow may be be used with less than 1% error for Mach numbers from zero to 0.1. This covers the range intended for most wind load coefficients. From Mach numbers 0.1 to 0.5 the incompressible pressure coefficients may be used if first multiplied by $\frac{1}{\sqrt{1-M^2}}$. This is the Prandtl-Glauert rule, see Ref. 2, p. 139. For larger Mach numbers, more elaborate methods must be used.

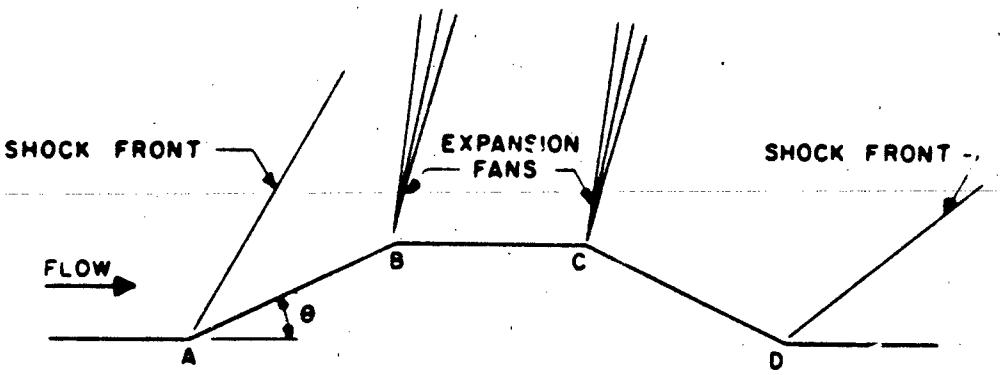


FIG. B.2 SUPERSONIC FLOW

In the supersonic case the flow pattern is illustrated in Fig. B.2. On hitting the corner at A, the flow forms a shock

wave which turns the oncoming flow abruptly, so it is parallel to AB. This causes a pressure rise. At B, the flow goes thru a Prandtl-Meyer expansion fan which again turns the flow, this time with a pressure reduction. At C there is another expansion fan and then a compression shock wave at D returning the flow to its original direction. The changes of pressure at each shock and expansion can be conveniently figured using Fig. B.8 thru B.11. The pressure is relatively constant on each of the faces AB, BC and CD, being of course greatest on AB. The shock at A is called an attached shock wave because it starts right at A. As the Mach number decreases toward one, there will be a certain Mach number (Fig. B.3) at which the attached shock will no longer be possible for the given angle O. Below this Mach number the shock wave is detached as shown in Fig. B.4 and the flow will be in the transonic range.

In the transonic flow shown in Fig. B.4, the flow is supersonic throughout except for the embedded subsonic region EFBAE. The initial flow is assumed supersonic, i.e., $M_0 > 1$, see Ref. 3.

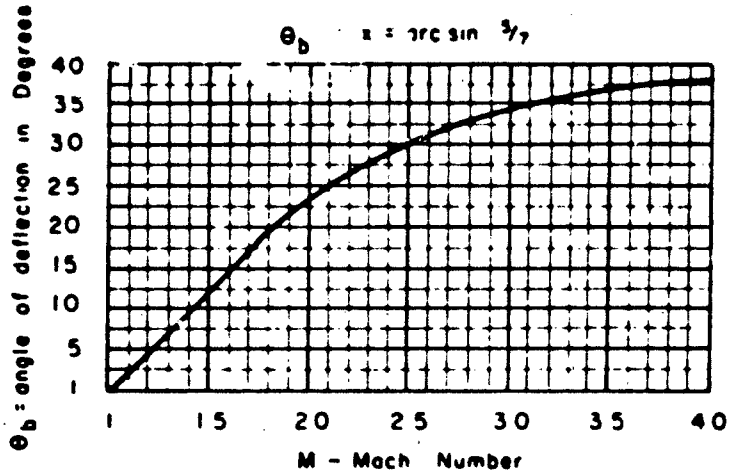


FIG. B.3 MAXIMUM DEFLECTION ANGLE FOR WHICH THE SHOCK WAVE WILL REMAIN ATTACHED. (REF. 5)

As the initial Mach number decreases to 1, the detached shock in Fig. B.4 forms further ahead of point A. When the Mach number falls below 1, the typical situation in the transonic range is as shown in

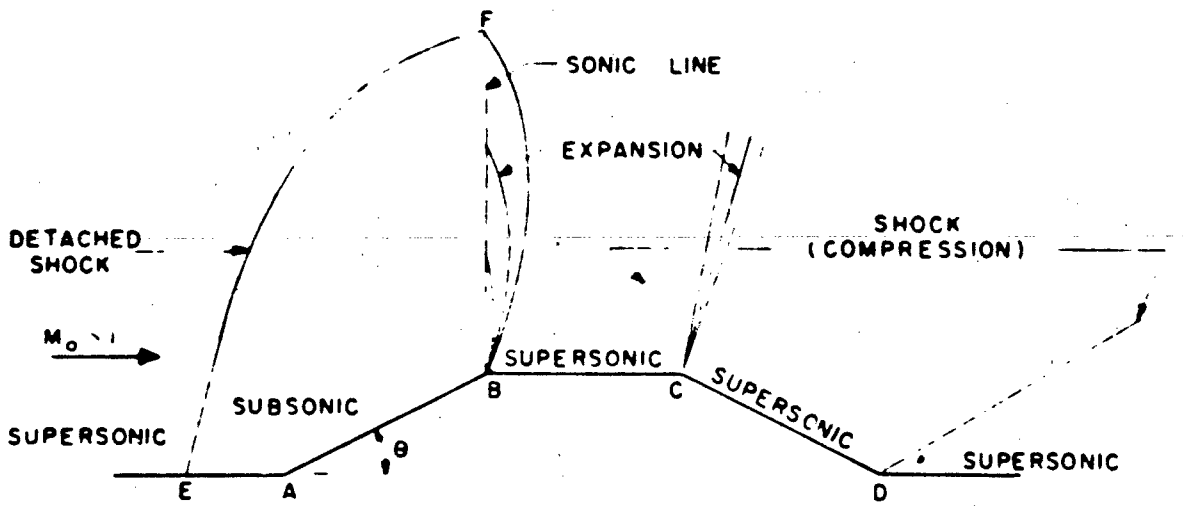


FIG. B.4 TRANSONIC FLOW ($M_o > 1$)

Fig. B.5 with one supersonic regions embedded in the subsonic flow. The conditions shown apply to Mach numbers not too close to one. As the Mach number increases and approaches one, the supersonic region grows finally covering the structure from B. to D. In this condition there would be a shock wave starting from D as in Fig. 3.4.

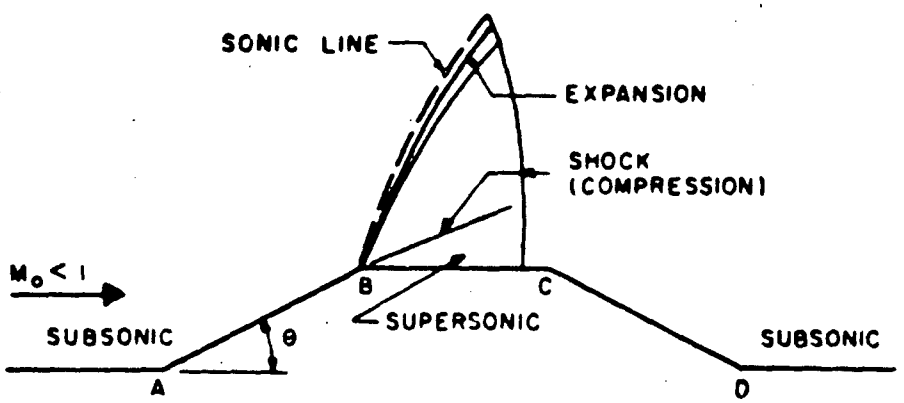


FIG. B.5 TRANSONIC FLOW ($M_o < 1$)

The flows shown in Figures B.4 and B.5 have certain features of interest in common. In both cases the pressure at A is equal to the stagnation pressure of the subsonic flow upstream of A. At B the local Mach number is always unity at the start of the expansion fan. These facts have been established experimentally and theoretically, see Ref. 6.

Further, it has been shown that the pressure distribution on the face AB is the same for a wide range of transonic flows, for a given angle θ, when the pressure is expressed in terms of the stagnation pressure rather than a pressure coefficient, see Ref. 7, p. 255. These facts are the basis for the following methods used in computing the pressure distribution for the cases at hand.

B.3 METHOD FOR COMPUTATION OF PRESSURES IN THE TRANSONIC RANGE

B.3.1 Cases In Which The Initial Flow is Supersonic.

The two highest pressure shock waves of 100 psi and 200 psi shock pressure yield an initial flow which is supersonic as shown in Table B.1. In these cases the conditions shown in Fig. B.4 apply.

The first computation is to find the stagnation pressure in the subsonic region. This may be conveniently done using Fig. B.8 and B.9. This stagnation pressure at point A, (Fig. B.6) is obtained by first determining the supersonic downstream pressure, psi, corresponding to the freestream Mach number, $M_0 = M_1$, from Fig. B.8 (using $\gamma = 1.4$), then using Fig. B.9 to determine the pressure at A, . For points between A and B, for the particular angle involved ($\theta = 26.6^\circ$) there for fortunately both theory and experiments available giving the ratio of the pressure at any point x to the stagnation pressure which occurs at A. These ratios are plotted in Fig. 16 of Ref. 5 and are summarized in Table B.2.

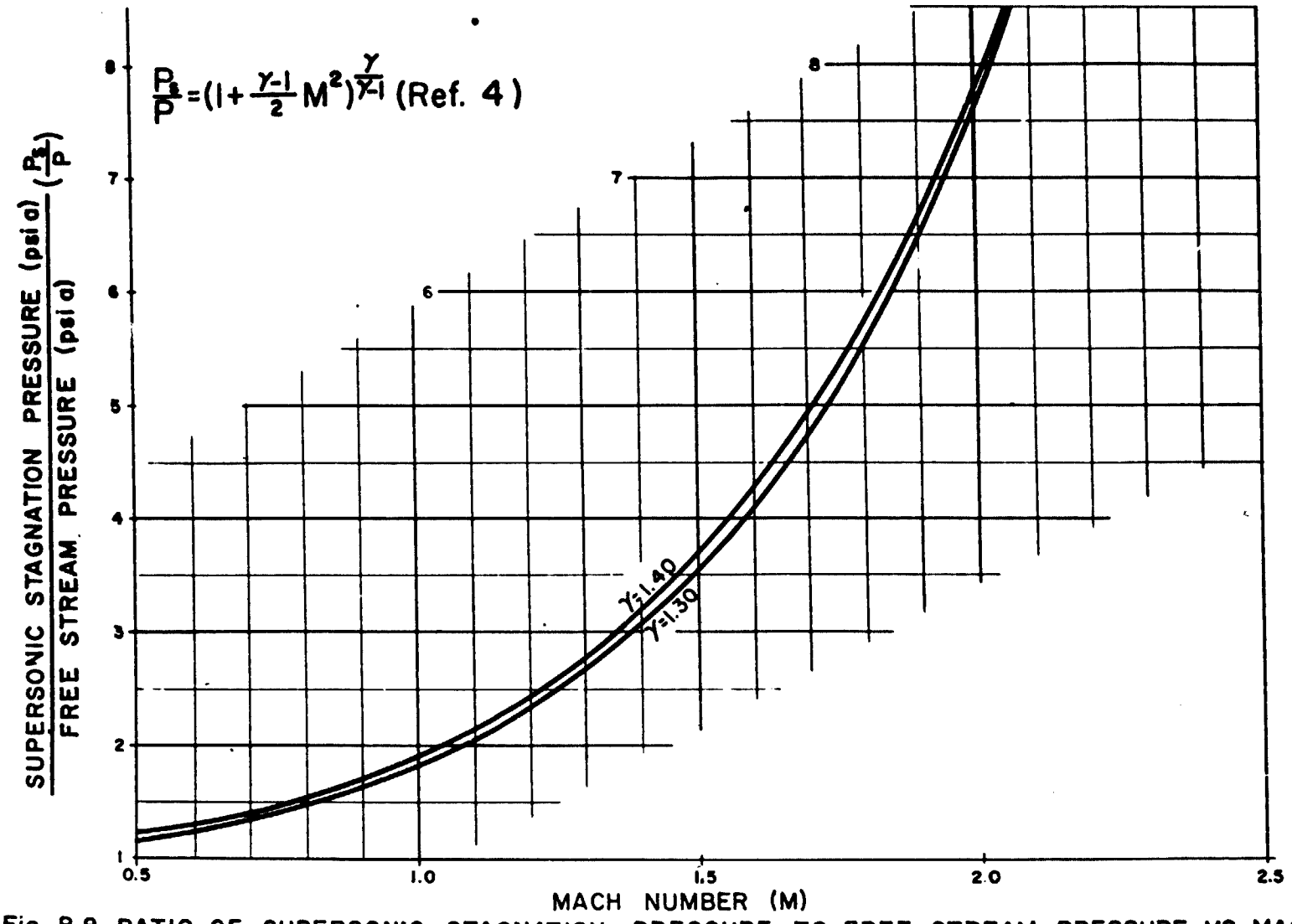


Fig. B.8 RATIO OF SUPERSONIC STAGNATION PRESSURE TO FREE STREAM PRESSURE VS. MACH. NO.

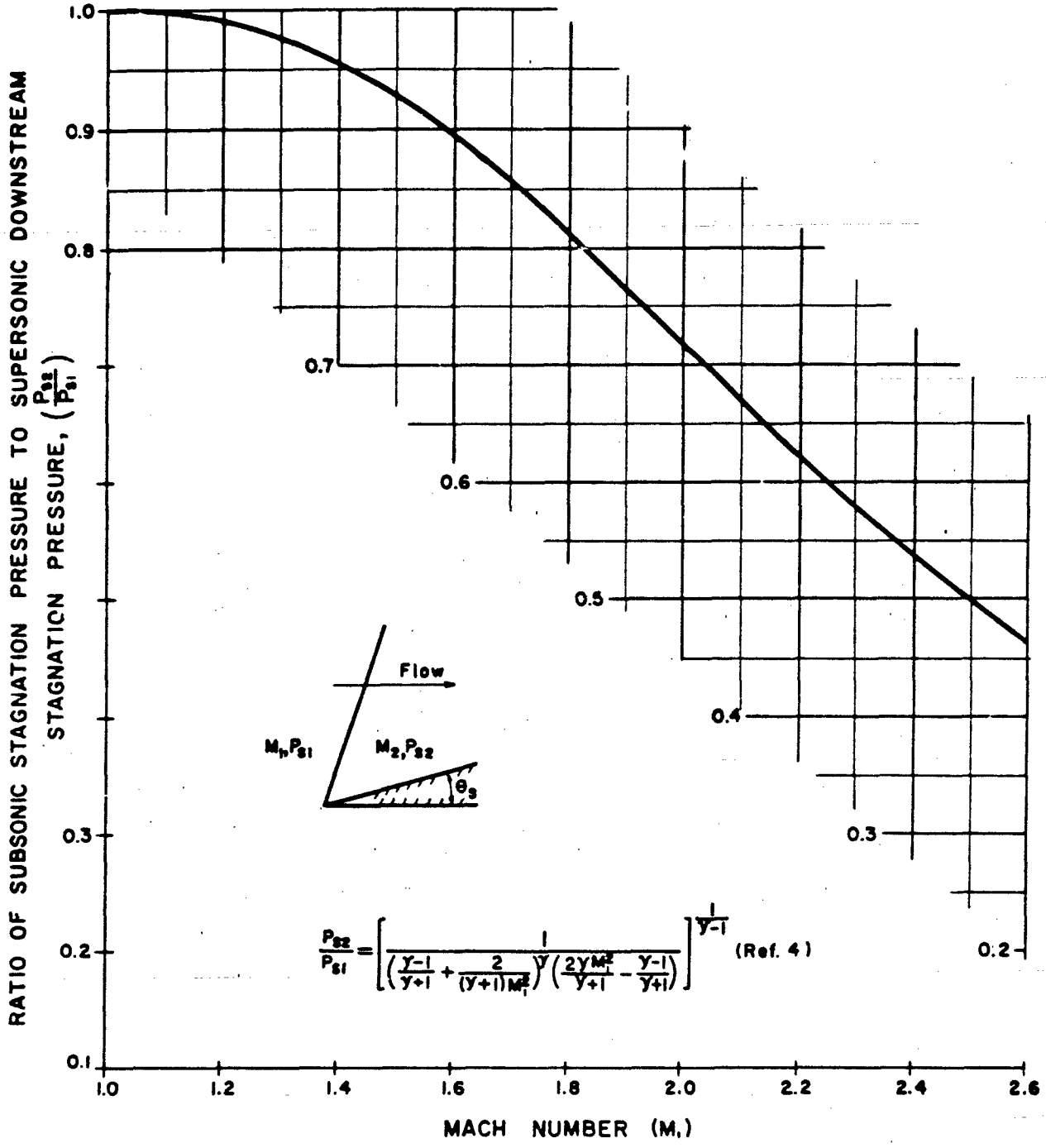


Fig. B.9 STAGNATION PRESSURE RATIO ACROSS A NORMAL PLANE SHOCK (psia)

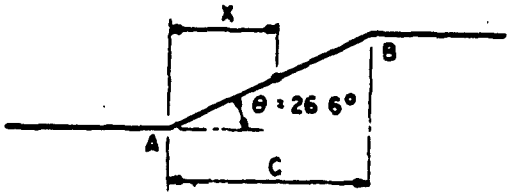


FIG. B.6 DEFINITION OF x and c

It will be noted that the experiments and theory in most of the references deal with wedges as shown in Fig. 3.7. The structures considered herein are effectively one half of the wedges tested.

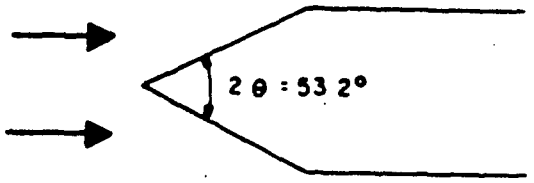


FIG. B.7 TYPICAL WEDGE PROFILE

TABLE B.2 $\frac{\text{Pressures at x, p}}{\text{Pressure at A, } p_s}$ for $\theta = 26.6^0$

(From Fig. 16 of Ref. (5))

$\frac{x}{c}$	$\frac{p}{ps}$
0	1
0.1	0.875
0.2	0.840
0.3	0.822
0.4	0.793
0.5	0.772
0.6	0.743
0.7	0.723
0.8	0.687
0.9	0.655
1.0	0.528

The test results and theory available are concerned primarily with the face AB which is the most heavily loaded region and the relatively precise data given in Table B.2 is applicable. Unfortunately, equally precise data is not available for the faces BC and CD. On the basis of examination of test results and of the underlying theory the following procedure is suggested as conservative and adequate, though lacking the same precision as the loads on AB.

The pressure at B, on the BC side of the corner may be computed by assuming there is a Prandtl-Meyer expansion fan starting from Mach number one on the downstream side of the corner as the net effect on an overexpansion and compensating compression at the corner. This pressure may be obtained by determining the Mach number, M_2, on the BC side of the corner corresponding to the deflection angle $\theta = 26.6^\circ$ from Fig. B.10 and then entering Fig. B.8 with this value to obtain the pressure, P . Along the face BC there may be some weak or even quite strong shock waves for which exact data is not available, but their effect will be to increase the pressure. A reasonable estimate for the cases being considered is that the flow is returned to the pressure of the original supersonic flow upstream of E by the time the corner C is reached. In the absence of exact data a linear distribution of pressure between B and C is assumed.

At C, the pressure on the downstream side may be estimated by assuming a Prandtl-Meyer expansion fan starting from the free stream Mach number. Along the face CD, it is suggested that the pressure be assumed uniform because this region is shielded from the influences that can cause pressure rise along BC. The pressure on CD may be obtained from Fig. B.10 and B.11 as follows: (1) enter Fig. B.10 with free stream Mach number to obtain the Prandtl-Meyer angle, ϕ, (angle thru which a supersonic stream is turned to expand from $M = 1$ to $M > 1$), (2) add ϕ to the deflection

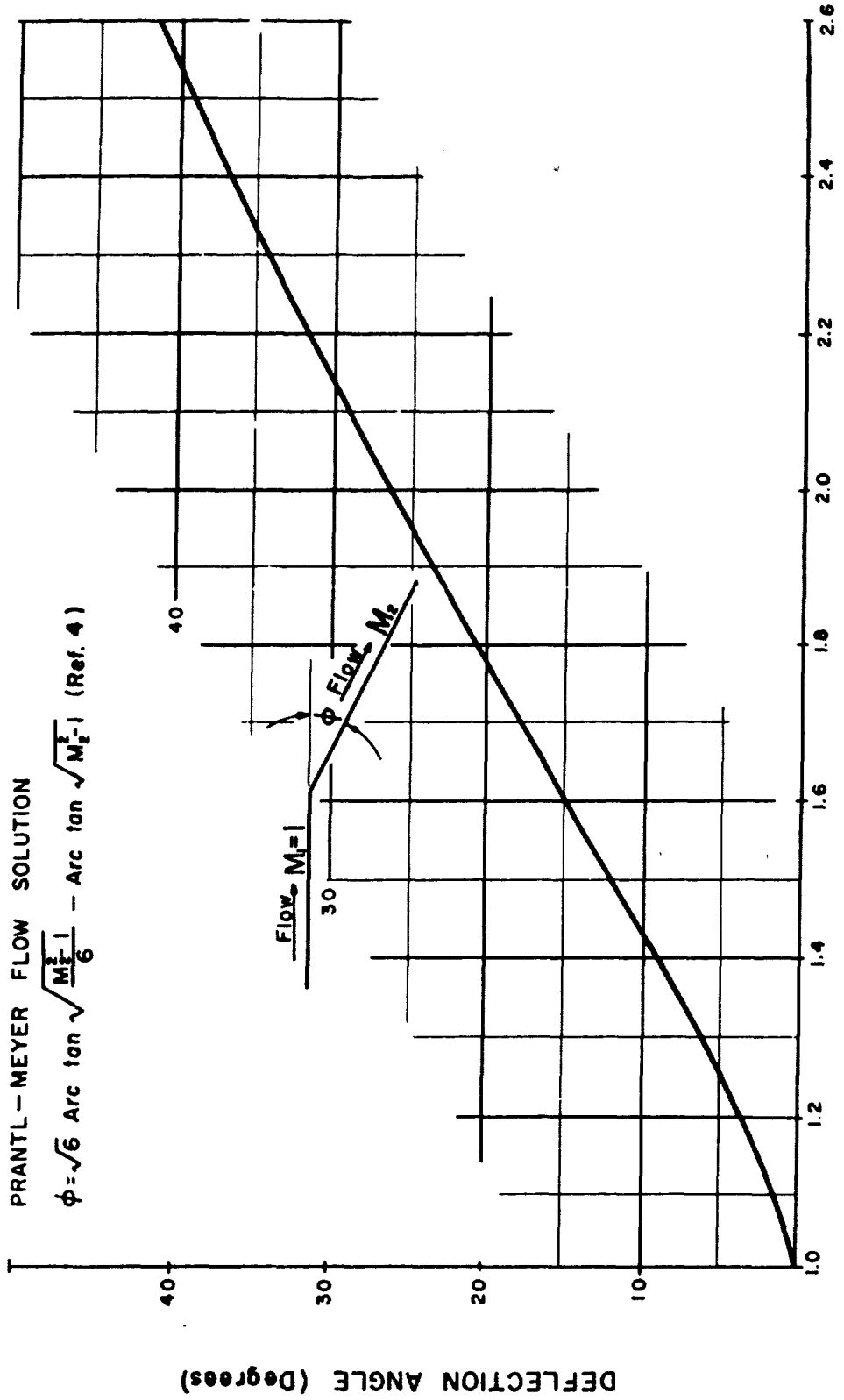


Fig. B.10 DEFLECTION ANGLE REQUIRED TO EXPAND TO A GIVEN MACH NUMBER

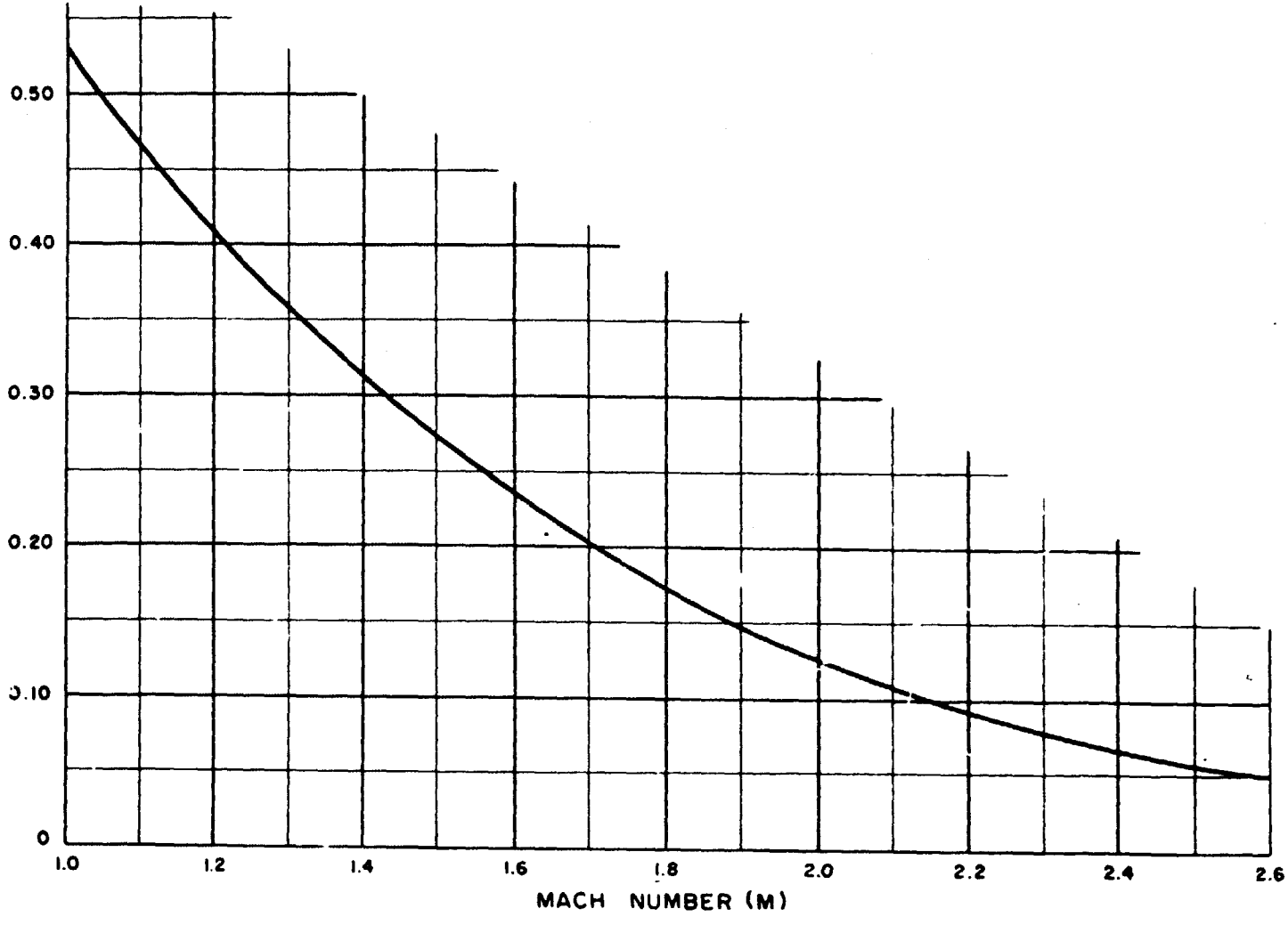


Fig. B.11 RATIO OF STATIC PRESSURE, p, TO TOTAL PRESSURE, p_t, vs. MACH NUMBER, M
(REF. 3)

angle (26.6° for our case) to obtain the Mach number on CD using Fig. B.10, (3) using this Mach number enter Fig. B.11 to obtain the ratio P/Pt where p is the static pressure on face CD and Pt is the total pressure downstream of C. Since there are only isentronic processes between A and D, Pt is the same as at A, compute p from the ratio p/Pt.

B.3.2 Cases In Which The Initial Flow is Subsonic

The shock waves of 25 and 50 psi in Table 1 have original Mach numbers less than one. In these cases, the pressure at A is the stagnation pressure given in Table B.1 and is obtained from Fig. 3.8 only by entering the figure with the free stream Mach number to obtain the pressure ratio.

The coefficients given in Table 8.2 apply for the region AB, using the stagnation pressure as given in Table B.2 for the angle $\theta = 26.6^{\circ}$.

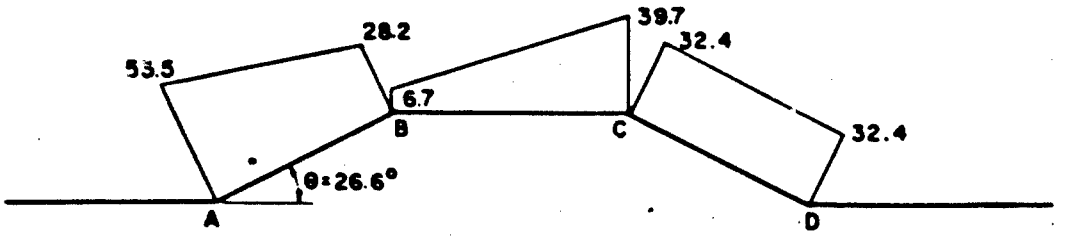
The pressure on the downstream side of B is computed assuming an expansion fan from Mach number one and may be obtained from Fig. B.9 and B.10 for $\phi = 26.6^{\circ}$ as for the supersonic case. A linear pressure rise is assumed from B to C, reaching the free stream pressure at C.

The downstream pressure at C is estimated according to there being a separation of the subsonic flow at the corner and with the help of experimental data (Ref. 8). Simple inviscid theory would indicate that the flow expands to zero pressure at

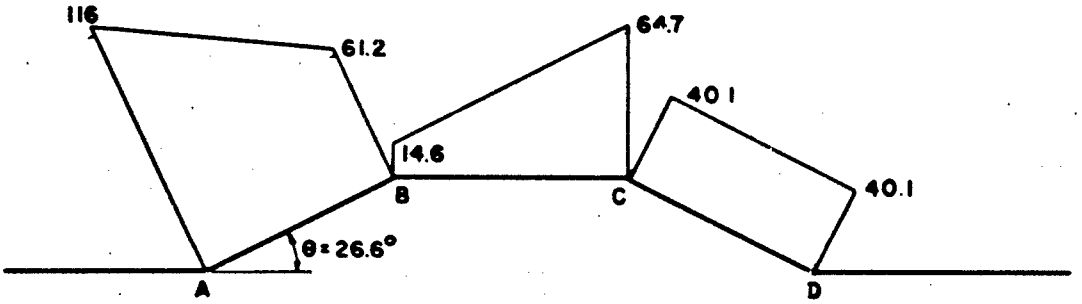
the corner and thereafter resumes free stream velocity. However, since for these Mach numbers of approach to an edge of such a large angle as that at C the flow separates, viscous effects can not be ignored (Ref. 8). The pertinent data in Ref. 8 (page 28 for station 12, 16) applies to a 30° flap deflection at an angle if attack of the flap of -9°. It would be desirable to have data for a leading edge flap deflection 26.6° and an angle of attack of the flap of 0° but the above data is the closest available at this time. The pressure coefficient, $P = (p-p_o)/q$ indicated by the above test data is between-0.6 and -0.7, where p = the static pressure (psia), p_o = free stream pressure (psia) and q = the dynamic pressure. From another standpoint, if we can apply data from a wedge to represent flow on a half wedge following a straight section, as we did on the forward face AB, then we can apply data from a sharp edged plate at an angle of attack of 26.6° to represent the flow around a sharp corner of 26.6°, with about the same validity. The data on pages 18 and 19 (zero flap deflection) of Ref. 8 show that the flow is separated and P is constant over the entire chord for $\alpha > 15°$, so it surely is also for $\alpha = 26.6°$. The value of P is about -0.6, and this is used for both the 25 and 50 psi cases in this report.

3.1 NUMERICAL RESULTS FOR THE GIVEN CASES

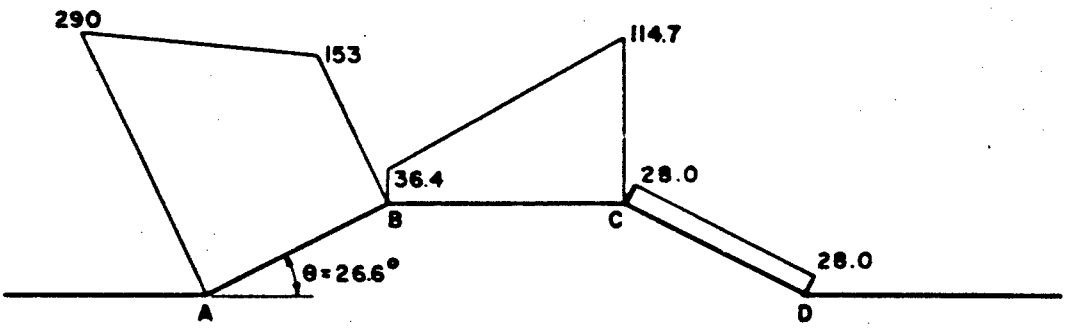
The absolute pressures in psi (absolute) are shown in Fig. 3.12 for the given shock waves of 25, 50, 100 and 200 psig,



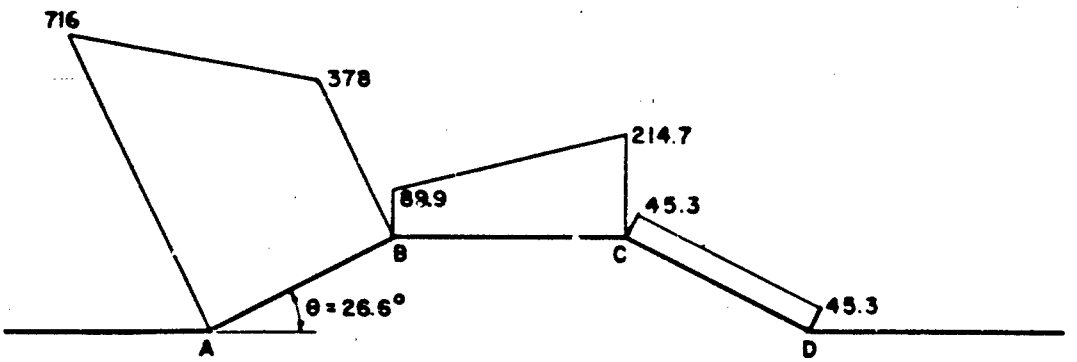
PRESSURES, PSI ABSOLUTE, FOR 25PSIG SHOCK WAVE



PRESSURES, PSI ABSOLUTE, FOR 50PSIG SHOCK WAVE

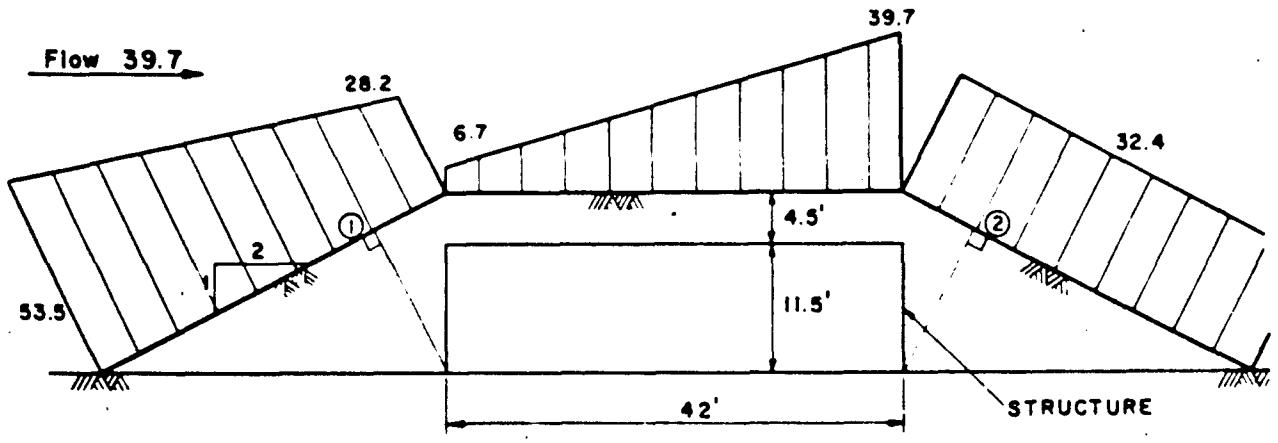


PRESSURES, PSI ABSOLUTE, FOR 100PSIG SHOCK WAVE

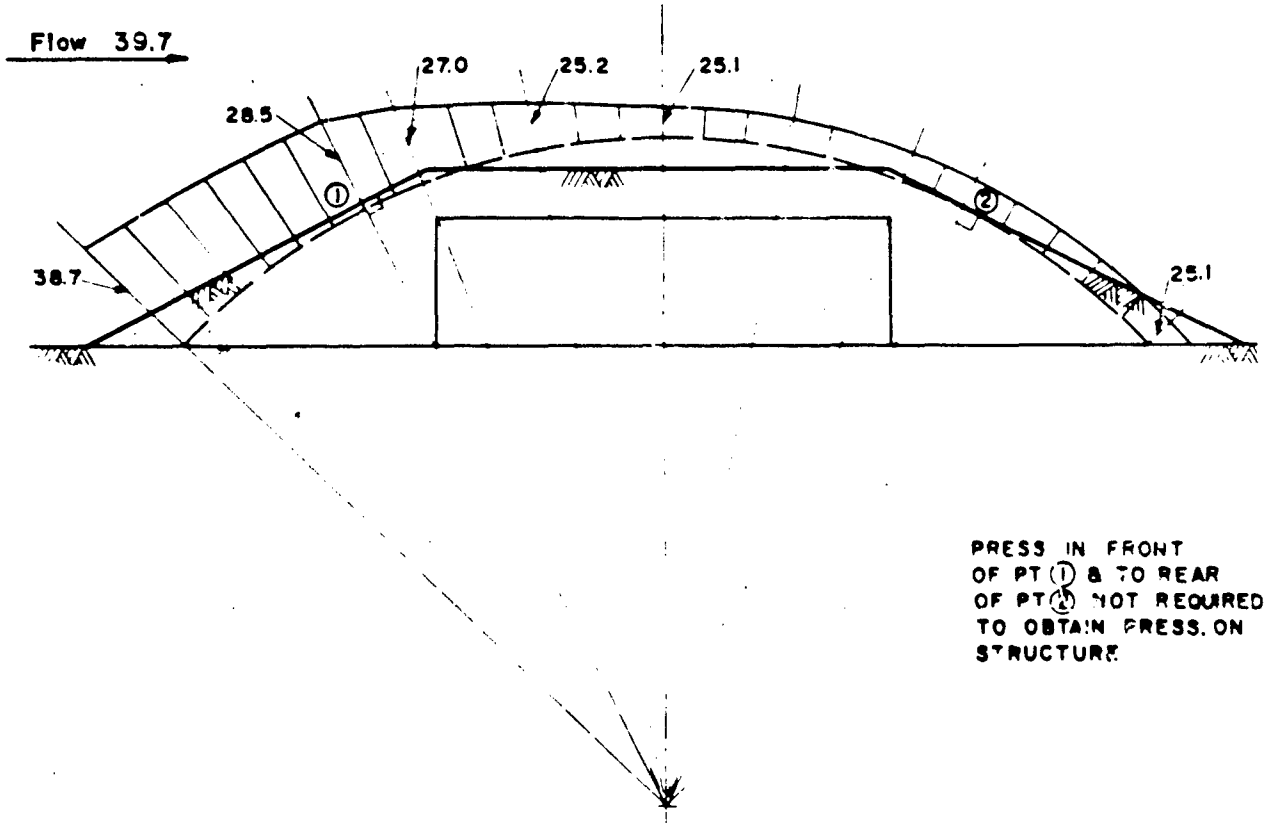


PRESSURES, PSI ABSOLUTE, FOR 200PSIG SHOCK WAVE

Fig. B.12 STEADY STATE PRESSURES FOR STRUCTURES IN Fig. B.1



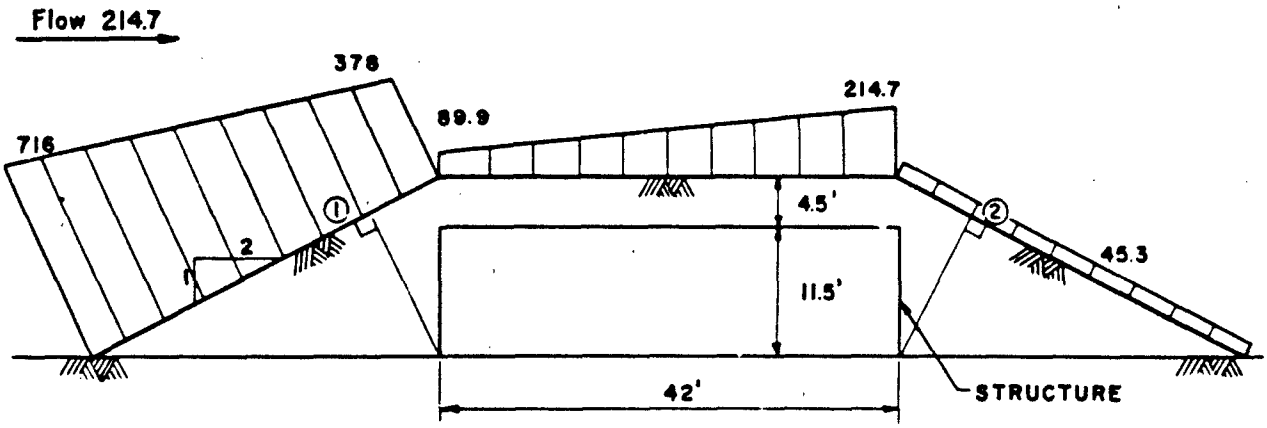
WEDGE METHOD



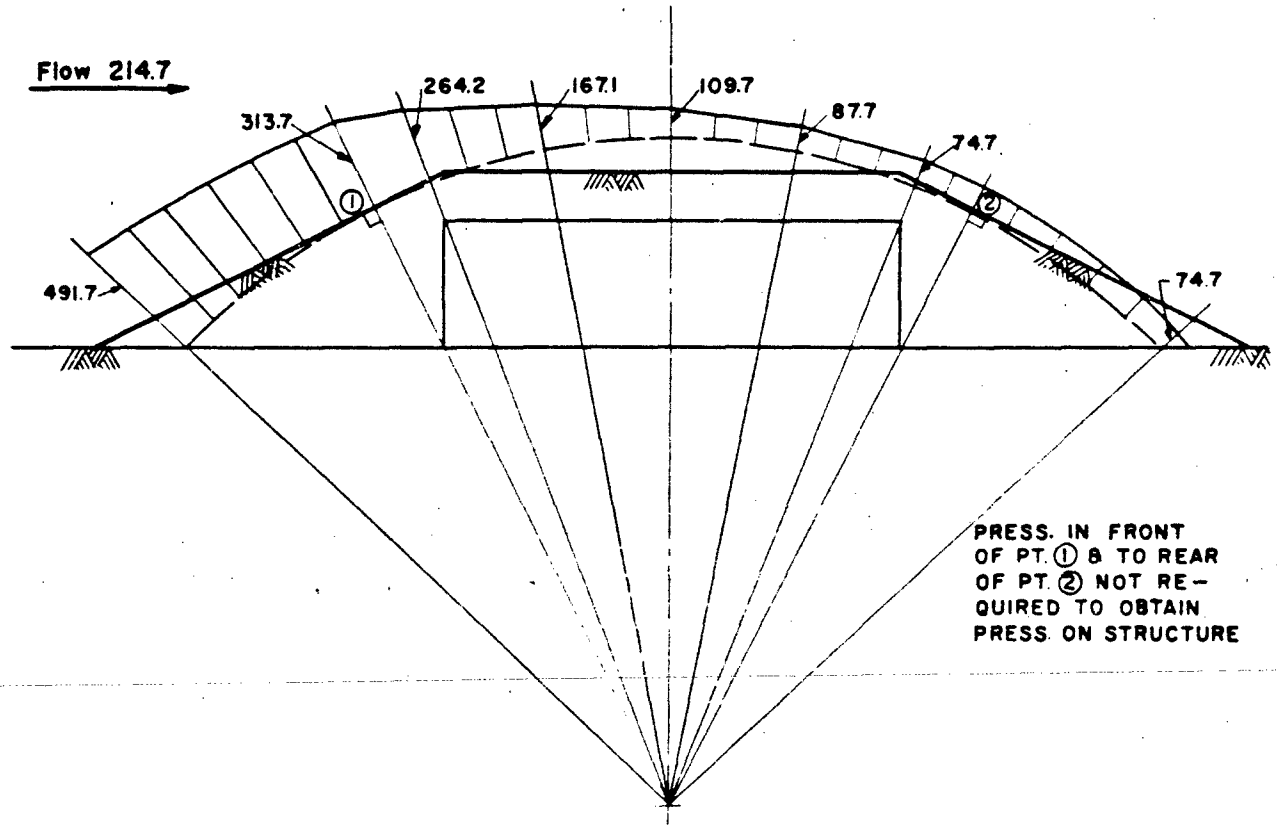
EQUIVALENT CIRCLE METHOD (MIT Manual)

NOTE: ALL PRESSURES ARE PSI ABSOLUTE

Fig. B13 COMPARISON OF WEDGE METHOD WITH EQUIVALENT CIRCLE METHOD
Press.= 25 psig



WEDGE METHOD



EQUIVALENT CIRCLE METHOD (MIT Manual)

NOTE: ALL PRESSURES ARE PSI ABSOLUTE

Fig. B.14

COMPARISON OF WEDGE METHOD WITH EQUIVALENT CIRCLE METHOD

Press.= 200 psig

respectively. The exact variation of the pressure along AB in each case may be found by applying the coefficients of Table B.2 to the pressure given for Point A in each case. For comparison, the pressure distribution obtained using the equivalent circle method described in the OCE Manual (Ref. 1) is shown for the 75 psig level, and the 200 psig level in Fig. B.13 and B.14. The values given in Figure B.12 are based upon a "flat top" shock but the preceding method is also easily applied to shocks which vary with time.

The pressures given are intended to apply to both of the structures shown in Fig. B.1 (a) and Fig. B.1 (b). The difference in the length of BC in the two cases will, in fact, make little difference to the pressure distribution and the available information does not provide any basis for computing these variations. It would be desirable to have a solution for flow over a double-wedge profile of 53° nose angle, but we have not been able to locate any data for this range.

B.5 REMARKS CONCERNING DOME OR CONICAL SHAPED STRUCTURES

The above analysis has been concerned with structures which are long enough compared to the dimension in the direction of flow to be considered two dimensional. A dome or conical shaped structure does not fall in this category and the coefficients suggested above should not be used for such cases, although this would certainly be conservative as far as the heavily loaded windward side is concerned.

Field measurements on full scale structures of this type were made during the 1957 nuclear test series conducted at the Nevada Test Site, but were not available at the time of this report.

References:

(1) "Design of Structures to Resist the Effects of Atomic Weapons", EM 1110-345-413 and EM 1110-345-420, Manual - Corps of Engineers, U. S. Army (Preliminary Draft).

(2) Liepmann, H. W. and Puckett, A. E., "Introduction to Aerodynamics of a Compressible Fluid", Wiley & Sons, 1947.

(3) Vicenti, W. G. and Wagoner, C.B., "Transonic Flow Past a Wedge Profile with Detached Bow Wave," Report 1095, National Advisory Committee for Aeronautics, 1952.

(4) Dailey, C. L. and Wood, F. C., "Computation Curves for Compressible Fluid Problems", Wiley & Sons, 1949.

(5) Miles, E. R. C., "Supersonic Aerodynamics", McGraw Hill, 1950.

(6) Bryson, A. E., "An Experimental Investigation of Transonic Flow Past Two-Dimensional Wedge and Circular-Arc Sections Using a Mach-Zehnder Interferometer", Report 1094, National Advisory Committee for Aeronautics, 1952.

(7) Griffith, W., "Shock Tube Studies of Transonic Flow over Wedge Profiles", Journal of the Aeronautical Sciences, Vol. 19, No. 4, April 1952, pp. 249-257.

(8) Cleary, J. W. & J. A. Mellanthin, "Wind-Tunnel Tests of a 0.16 Scale Model of the X-3 Airplane at High Subsonic Speeds - Wing and Fuselage Pressure Distribution", NACA RM A50D07, June 22, 1950.

(9) Liepmann, H. W. and Bryson, A. E., "Transonic Flow Past Wedge Sections", Journal of the Aeronautical Sciences, Vol. 17, No. 12, Dec. 1950, pp. 745-755.

(10) Ames Research Staff, "Equations, Tables & Charts for Compressible Flow", NACA Report 1135, 1953.

(11) Spreiter, J. R., "Theoretical & Experimental Analysis of Transonic Flow Fields", NACA - University Conference on Aerodynamics, Construction and Propulsion, Vol. II - Aerodynamics, October 20-22, 1954.

(12) Anon, "Transient Drag and Its Effect on Structures, Final Report, Project MR 1013, American Machine and Foundry Company, February 25, 1955 (Confidential).

(13) Spreiter, J. R. & A. Y. Alksne, "Thin Airfoil Theory Based on Approximate Solution of the Transonic Flow Equation", NACA, TN 3970, May 1957.

APPENDIX C - RADIATION ATTENUATION CRITERIA FOR SHELTERS AND PRESSURE CRITERIA FOR ENTRANCES

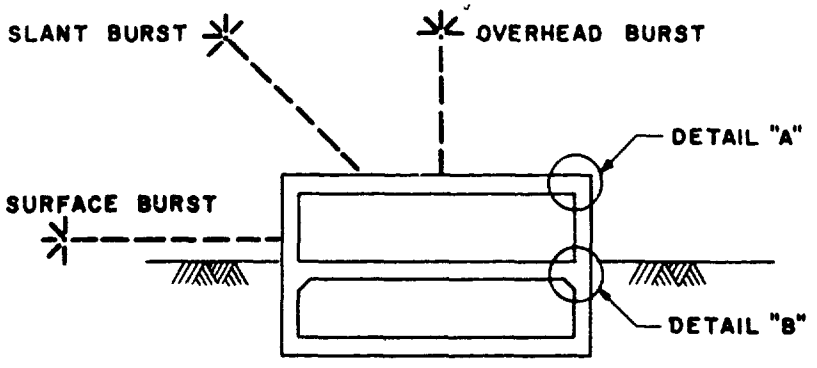
C.1 RADIATION ATTENUATION CRITERIA

C.1.1 General

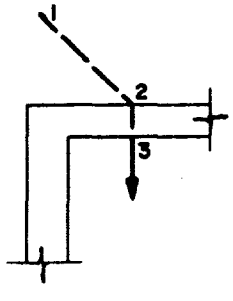
The initial gamma and neutron radiation levels for the design weapons listed in Chapter 1 - Section 1.5 and the attenuation factors for concrete and earth were based upon the documents listed in Chapter 1 - Section 1.5. The radiation path used for determining the earth and for concrete shielding necessary to reduce the initial radiation to the prescribed 50 roentgen level within the shelter areas was taken as that which provides the least attenuation, neglecting any possible reduction due to an acute angle of incidence of the exterior radiation. This criteria was recommended by the OCE. The relative locations of detonation and various paths considered are illustrated in Figure C.1.

C.1.2 Entranceways

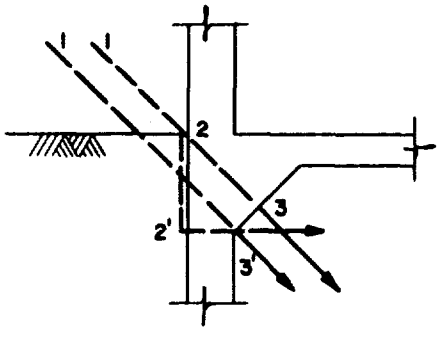
There is very little quantitative data on the effect of baffles turns or air scattered radiation. This effect was included in the design of the shelter areas by assuming that the radiation entering by way of stairways is reduced by 90% at each right angle turn (recommended by O.C.E.).



TYPICAL STRUCTURE



DETAIL "A"



DETAIL "B"

Fig. C.1 ASSUMED RADIATION PATHS FOR DETERMINATION OF REQUIRED SHIELDING

C.2 PRESSURE CRITERIA FOR ENTRANCES

The design blast loading for the design of the entrances for the buried and above-ground earth covered structures was assumed equal to the side-on pressure. The blast doors of the above-ground earth covered structures were designed for side-on pressure and the blast doors for the buried structures were designed for reflected pressures.[1]

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1 OPERATION UPSHOT KNOT HOLE, Project 3.7, "Air Blast Effects on Entrances & Air Intakes of Underground Installations", 1 May 1954 Draft, pg. 71.

APPENDIX D - DYNAMIC BEHAVIOR OF FOUNDATION ELEMENTS

D.1 INTRODUCTION

In determining the dynamic load effect upon foundations it is necessary to know the shape of the applied load, the resistance-deflection function (stiffness) and mass of the foundation member. When these three terms are known, the resistance-time and deflection-time solutions are obtained by solving the equation of motion. Several methods for solving this equation and the computation of the equivalent mass, are described in the C of E Manual.

The shape of the load-time function depends upon the applied load, F (t), soil resistance, R (t), and the mass of the structure plus the soil mass (above and below the foundation) affected by the applied load. The resistance-time and deflection-time solutions are obtained by assuming rigid body motion solving the equation $F(t) - R(t) = m_e \ddot{x}(t)$ where m_e is the equivalent mass of the system and $\ddot{x}(t)$ is the acceleration. The stress condition below a structure similar to that shown in Figure D.1 is complicated by the extensive surface load rather than the more conventional type of load limited to the structure only. One approach to the problem is to assume that the foundation member is not affected by the surface load outside the limits of the structure. Unfortunately, there is no test data available to justify this

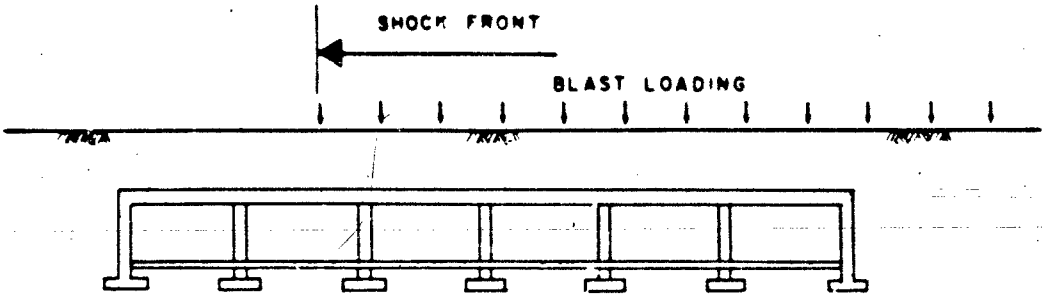
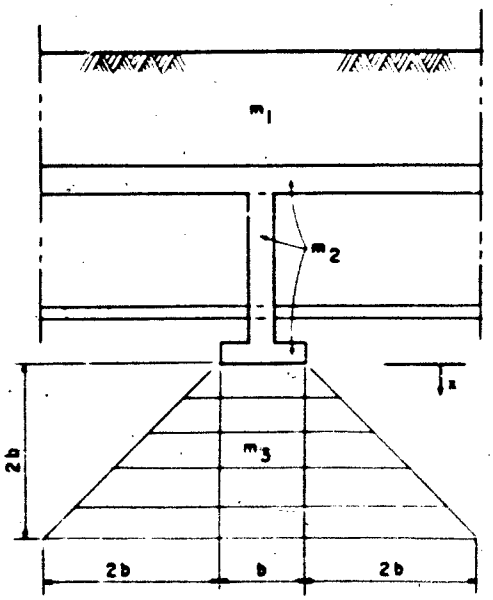
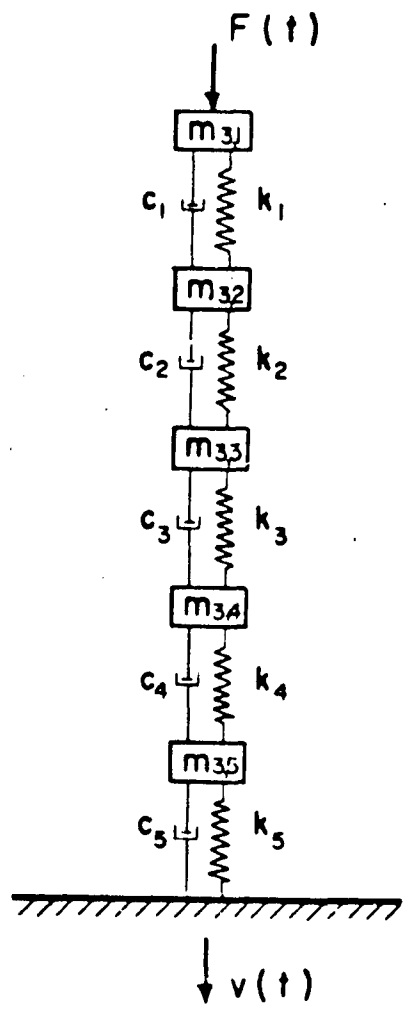


Fig. D.1 TYPICAL BURIED STRUCTURE WITH INDIVIDUAL FOOTINGS



① i	② x/b	③ SOIL PRESSURE	④ AVG. SOIL PRESSURE	⑤ % DEFECTION = ④ ÷ Σ ④
0	0	1.0		
			0.655	0.583
1	0.4	0.309		
			0.229	0.204
2	0.8	0.148		
			0.118	0.105
3	1.2	.087		
			0.072	0.064
4	1.6	0.0[illegible]		
			0.049	0.044
5	2.0	0.040		
Σ			1.123	1.000

Fig. D.2 STRESS AREA BELOW ISOLATED SQUARE FOOTING



m_{3i} = mass of earth segment between i and i−1 (Fig D2)

k_i = stiffness of earth mass between i and i−1

C_i = damping coefficient of earth mass between i and i−1

v(t) = velocity pulse estimating overall ground motion at depth 2b below building

F(t) = applied load

Fig. D.3 SCHEMATIC REPRESENTATION OF EARTH WEDGE BELOW FOOTING

approach and therefore it was decided to design the foundations of the contract structures in accordance with the presently accepted criteria, i.e. to design for the applied load, neglecting dynamic settlement.

D.2 PROPOSED SOLUTION

The proposed method of solution using the above simplified procedure is given below for a typical interior square footing similar to the type illustrated in Figure D.1. It is assumed that the footings are spaced far enough apart that the effect of adjacent loaded footings is negligible. The proposed solution is as follows:

1. Compute the applied force F (t) using the methods described in the C of E Manual.
2. Compute the equivalent mass of the system,

$m_e = m_1 + m_2 + m_{3e}$.

where m_1 = mass of earth above structure

m_2 = mass of structure excluding "floating" floor slab

m_{3e} = equivalent mass of earth wedge below footing

m_3 = mass of earth wedge below footing

The volume of earth below the structure affected by the footing load is assumed to have the dimensions shown in Figure D.2. Compute the average stress intensity at each of

the indicated levels and tabulate in Columns 3 and 4 of Figure D.2. The effect of closely spaced adjacent footings can be accounted for by adding the stresses at the overlapping levels. The percentage of the deflection taking place in each increment of depth is proportional to the average stress intensity on the segment divided by the soil modulus of elasticity. Assuming, for simplicity, a homogeneous soil and constant modulus, the perdentage of deflection is computed and tabulated in column 5. The earth wedge can be represented schematically, as shown in Figure D.3 by a series of masses and springs. By "Rayleigh's Method"[1] of equating potential and kinetic energy, the fundamental period of the earth mass is found, and consequently the equivalent mass of the earth wedge is computed as $m_{3e} = 0.10m_3$.

($m_{3e} = 0.25m_3$ for continuous footings)

3. Compute the load-deflection function for the soil by one of the methods described in Soil Mechanics Texts.[2]

4. Solve the equation of motion of the total system for the resistance-time function of the soil.

5. Analyze the footing member using the resistance-time function from Step 4 as the applied load.

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1 Timoshanko, S.; "Vibration Problems in Engineering", Second Ed.

2 Terzaghi & Peck, "Soil Mechanics in Engineering Practice".

APPENDIX E - PROCEDURE FOR DESIGN OF SHEAR WALL STRUCTURES - ITEMS 1, 2 and 3

E.1 DESIGN PROCEDURE FOR SHEAR WALL STRUCTURES

The following is an outline of the procedure used for the design of the shear wall structures of this contract, items 1, 2 and 3.

1. Design exterior walls of structure for the front wall loading and determine the lateral dynamic reactions of the front and back walls on the structure. Design exterior wall footings.

2. Check structure, statically for rigid body sliding and overturning using the dynamic reactions of the wall and roof panels. Check maximum soil pressures developed under the footings and revise footing sizes if necessary.

3. Analyse the shear walls for elastic and plastic behavior to carry the net front wall and rear wall dynamic reactions assuming a dynamic load factor of 1.50 unless a smaller value is indicated by a dynamic analysis assuming a fixed base. This value is based upon shear wall response values obtained in elastic range analysis of several shear wall structures under comparable conditions and appears to be reasonable for the structures in question. The use of a dynamic load factor in place of a complete dynamic analysis is necessary in order to reduce the design time to a reasonable length. Assume that all shear walls deflect the same distance, hence the total lateral load on each shear wall is proportional to the relative

stiffness of the shear walls. This assumption, which makes it possible to analyze the dynamic behavior of all shear walls simultaneously, is equivalent to the standard assumption in building design that the roof and floor slabs act as rigid diaphragms. The effect of the slab flexibility may be included if desired, but the added reinforcement is seldom justified. The stiffness of the end shear walls in the elastic range is arbitrarily reduced fifty percent because of the effect of the simultaneous normal blast loads acting upon the end walls.

4. The roof and floor systems, columns, and column footings are designed to carry the vertical blast loads plus the conventional design loads as applicable. In designing the roof and floor systems, the roof and floor slabs are used as deep beams to transmit the horizontal front and back wall dynamic reactions to the shear walls. The maximum stresses in the roof slab under the combined slab and deep beam actions do not occur together and interaction formulae are not used in the design. The designer has the option of designing the roof slab under the vertical roof overpressure for elastic and elasto-plastic action[1] only or for plastic behavior. If the roof slab under the vertical loading is designed for elastic and elasto-plastic action only, the slab reinforcing steel may be assumed effective for the deep beam behavior for both flexure and shear. However, if the roof slab is designed

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[1] C of E Manual--Chapter 9, Section 9.07, Step 2.

for plastic action under the vertical loading, the slab reinforcing steel may not be considered effective for deep beam flexure, and separate steel must be provided as required. The latter method was being used by Ammann & Whitney for the design of Items 1, 2 and 3.[2] Analyze the roof and floor slabs as deep beams, for elastic and plastic behavior, to carry the net front wall and rear wall dynamic reactions using a dynamic load factor of 1.50 unless a smaller value is indicated by a dynamic analysis assuming a fixed base. The design of the floor slab directly above the foundation should include any additional horizontal load the slab may have to carry as a result of insufficient frictional capacity below the shear wall footings. The roof and floor slabs acting as horizontal deep beams are checked for shear using the following criteria:

1st crack load:

$$V_c = 0.1 f'_c \, Lt$$ (C of E Manual--equat. 4.50)

Ultimate Load:

$$\text{Vult.} = \frac{0.1C}{\frac{P}{C} + 0.1} + \frac{2.1P}{\frac{P}{C} + 0.6} \quad \text{(1-story}$$

$$\text{Vult.} = \frac{0.1C}{\frac{P}{C} + 0.1} + \frac{2.8P}{\frac{P}{C} + 0.6} \quad \text{(2-story)}$$ (C of E Manual equat. 4.55)

For $\frac{P}{C}$ 3.26 use $\frac{P}{C} = 3.26$ [3]

These equations are to be increased to account for rapid strain rates.

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[2] Recommended by Ammann & Whitney at Conference on September 3, 1955, attended by representatives of O.C.E., M.I.T., and A & W.

[3] Recommended by Prof. Benjamin at Oct. 27, 1955 conference at A & W attended by representatives of O.C.E., M.I.T., Stanford & A & W.

The ultimate deflection is given by ult.$\delta = 24 \frac{H}{L} \delta_c$

Where δ_c is the deflection at first crack.

Since the empirical data from which this formula was devised was limited to an L/H ratio between 0.9 and 3.0 it is arbitrarily assumed that for L/H ratios greater than 3 it is adequate to use L/H = 3 for use in the ultimate deflection expression for the structure being designed ($x_{ult} = 24 \frac{H}{L} x_{cr}$)

5. Design the front and back walls to carry the maximum net vertical roof and footing forces to the front and back edges respectively of the shear walls. The maximum shears and moments in the floor and wall elements as deep beams are determined by a moment distribution analysis. The horizontal floor slab deep beam reactions obtained from the moment distribution analysis are compared with the maximum shear wall reactions obtained in Step 4 to check the accuracy of the previous assumption. The shear walls and floor slabs are reinforced to resist the largest of the two stresses obtained in this step and in step 3.

6. In view of the many variables which tend to affect the dynamic response of shear wall structures it is recommended that, sufficient two-way reinfordement be provided to ensure an ultimate capacity equal to the computed response when the computed shear stress in the shear walls is equal or greater than 75% of the cracking stress ($0.10 f'_{dc}$).

APPENDIX F - DESIGN CRITERIA FOR ARCHES AND DOMES

F.1 ARCHES

The method of analysis used for the design of the above ground earth covered arch structures is similar to the procedure illustrated in the C. of E. Manual except for the modifications listed below.

1. The blast loadings on the above ground, earth covered arches were computed using the method described in "Transonic Pressures on Above Ground Earth Covered Structures", Appendix B. The use of this criteria results in relatively "long duration" deflection mode loads rather than the short duration "impulse" type load used in the C. of E. Manual. The deflection mode curve was approximated by trial and error by an idealized triangular load, and the response was determined using the design charts found in Fig. 5.28 and 5.29 of the C. of E. Manual.

2. The arches were designed and analyzed as fixed arches rather than pinned arches. The arch reinforcement for the above ground earth covered type was chosen to produce almost simultaneous formation of the yield hinges (four) at the springing line and within the arch proper.

3. The maximum sidesway of the above ground, earth covered semicircular arches at the crown was limited to 1/50 of the centerline radius (corresponding to a maximum radial displacement, X_m, at 45 degrees from the springing line equal to about 1/45 of the centerline radius as compared to the C. of E. criteria which recommends a maximum radial deflection equal to 10 times the elastic radial deflection). For the structure considered (inside radius equals 13.42 feet) the value of X_m was approximately 3.6 inches and the X_m/X_e ratios were between 1 and 2.

F.2 DOMES

The method of analysis used for the design of the doors is similar to the procedure illustrated in the C. of E. Manual except for the modifications listed below.

1. The blast loadings on the above ground earth covered domes was estimated using the method described in Appendix B.

2. The domes were analyzed as fixed rather than pinned and the edge bending included.

3. The deflection mode effect was computed using a pressure distribution $Z = p \sin \phi \cos \theta$ [1] rather than the uniform distribution indicated in the C. of E. Manual. It should be noted that the values indicated in the C. of E. Manual for the uniform deflection mode are not correct.

4. It should be noted that a substantial savings may be achieved in the floor slab design for both the dome and arch type structures if the soil properties are known and the slab is analyzed as a slab on an elastic foundation. This of course, was not done in this study.

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[1] Timoshenko, "Plates and Shells", Pg. 374.

APPENDIX G - CHANGES IN DESIGN CONCEPTS SUBSEQUENT TO DESIGN STUDY

G.1 GENERAL

The blast design of the structures summarized in this report were based upon the preliminary draft of the C. of E. Manual. Several additions and revisions have already been made in the current copy of the Manual. Some of these revisions and their effects on the design study are discussed below. Also, some additional concepts not yet incorporated in the current manual and not included previously in this report, are discussed.

G.2 REVISED SHEAR WALL CAPACITY

The equations for the ultimate resistance of shear walls for one and two story buildings used in the design are as indicated in step 4 of Appendix E. These equations have been revised in the current C. of E. manual in accordance with additional tests performed at Stanford University. The revised equation, $R_u = \frac{0.1}{\frac{P}{C} + 0.1} + \frac{2.2P}{C}$ indicates a larger ultimate capacity. Fig. G.1 shows that the ultimate shear wall capacity computed by the current equation may be as much as 4 times the value indicated in the preliminary report (within the range reported), consequently the shear wall reinforcement indicated for items 1, 2 and 3 in this study is overdesigned. In connection with the current equation it is felt that considerable additional shear wall research is necessary, such as (1) the extension of the parameters to include larger L/H and P/C ratios, (2) a study to determine the effect of varying the shear wall spacing on the shear distribution along the top of the wall and shear wall capacity, particularly for larger L/H values, (3) a study of the effect of vertical loads on

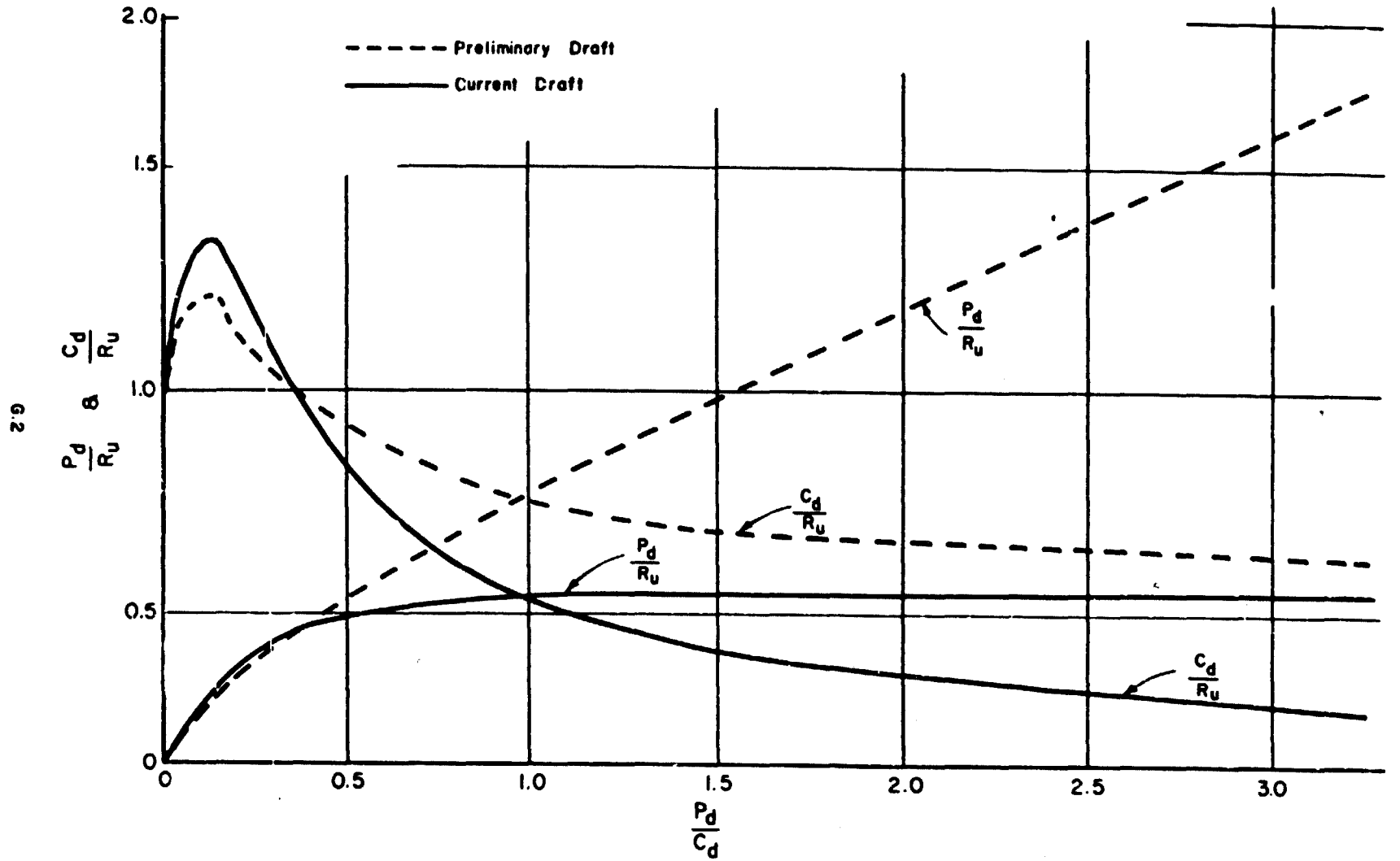

Fig. G.1 COMPARISON OF ULTIMATE RESISTANCE OF SHEAR WALLS AS CALCULATED FROM THEORETICAL EQUATIONS OF PRELIMINARY & CURRENT DRAFT OF C OF E MANUAL.

the shear wall capacity, (4) a study to determine the effect of the overturning moments produced by upper story shears on the shear capacity of a lower story panel.

0.3 REVISED BLAST PARAMETERS

Several revisions and/or additions have been made in the available reference documents for the blast parameters since the completion of this study, eg., (1) revision of shape and duration of the incident pressure curve, (2) revision of radiation data, (3) addition of dynamic pressure parameters for non-ideal conditions. The study results should not be appreciably affected by any of these changes except for the drag sensitive above ground arch structures which should require some additional reinforcement particularly at the 25 and 50 psi levels.

0.4 GROUND SHOCK EFFECTS

Procedures are now available to estimate the accelerations and displacements of the free field ground medium. These, in turn, may be used to predict the acceleration and the displacements of structures and equipment. The study results should not be appreciably affected by this additional input.

0.5 REVISED DIAGONAL TENSION CRITERIA

The C. of E. Manual, at present, does not have the latest recommendations on diagonal tension. To modify the study to conform to the latest criteria may require addition or reduction, depending on the particular member, of shear reinforcement to that indicated by the study but should otherwise not appreciably effect the study results.

G.6 WALL PRESSURES

The full "hydrostatic" pressure prescribed by OCE for this study results in an upper limit design for the buried structures, consequently a reduction in the wall thicknesses and reinforcement can be expected where the wall pressures are reduced to conform to a given friction angle. The ratio of the actual wall pressures to the surface pressures may vary somewhat as follows:

Cohesionless soils, damp or dry	0.25
Unsaturated Cohesive Soils, Stiff Consistency	0.35
" " " , Medium "	0.50
" " " , Soft "	0.75
Saturated Soils	1.00

G.7 REVISIONS FOR BURIED ARCH DESIGN

The C. of E. manual recommends that only compression mode effects be considered on buried arches. Complete burial, however, is a function of the earth cover, the overpressure level, and the interior angle of the arch. Depending on those parameters, some portion of the full deflection mode should be added to the design. For the buried arches considered in this study it is expected that a small cost increase due to additional arch reinforcement will be incurred if this additional load is included. It is felt that some additional work on shallow buried arch structures may be justified, such as (1) a study of the importance of the "crown type" deflection mode (vertical deflection) which not considered at present and (2) a study of the special problems associated with "flat" arches.

G.8 REVISED PRESSURE IN BELOW GROUND ENTRANCES

Evaluation, subsequent to that used for the design of below ground entrances in this study, has indicated that the reflected pressures in entrances may be significantly lower[1] (approximately twice the peak incident pressure) than the theoretical reflections originally assumed. Consequently the blast door costs for these entrances may be reduced accordingly. In this connection it should be noted that research is still being done which may eventually provide a more complete explanation of the phenomena associated with entryway pressures.

[1] Operation Upshot Knothole, Project 3.7, "Air Blast Effects on Entrances and Air Intakes and Underground Installations", WT 726, pg. 137.